THE CARBOHYDRATE-NITROGEN RELATIONSHIP IN TOMATO PLANTS, AS INFLUENCED BY SUCROSE AND UREA FOLIAGE SPRAYS

D. A. Shaw
April, 1953

Department of Plant Science
University of Alberta

The Carbohydrate-Nitrogen Relationship in Tomato Plants, As Influenced by Sucrose and Urea Foliage Sprays

(Abstract)

Two field experiments, three greenhouse trials and a few tests conducted with use of growth chambers were utilized in investigating the influence of urea and sucrose foliar sprays on tomato plants, applied alone and in combined sprays.

Evaluation of the influence of these foliar spray treatments on plant carbohydrate and nitrogen nutrition was attempted by means of: (a) colorimetric tests for soluble carbohydrates and soluble nitrogen, utilizing a Fisher electro-photometer; (b) microchemical tests for starch in plant stems; (c) refractometer tests for total soluble solids content of fruits; (d) plant height and spread measurements; (e) fresh and dry-weight yields of plant parts; and (f) visual observations on general plant development under the treatments imposed.

Results indicate that sucrose applied to foliage with urea mitigates the burning influence of urea alone, the latter effect being most pronounced at low light intensities and high levels of temperature and relative humidity. The C/N ratio in tomato leaves was depressed when urea was applied as a leaf spray, with or without sucrose addition, compared

to that in plants receiving nitrogen only through the roots. Addition of sucrose to the urea spray mixture apparently acts to prevent leaf-burning by reducing the initially high rate of urea absorption, while tending to prolong the period of absorption. No direct evidence for absorption of sucrose from foliar spray was established, but in general tomato plants were found to absorb leaf-fed urea nitrogen just as well as soluble nitrogen applied to the roots. Combining sucrose with urea on foliage under low winter light conditions resulted in unfavorable growth responses, which included: (a) delays in the onset of fruit ripening; (b) failure of fruit development beyond the initial stages of sizing; (c) depressions in fruit yield; (d) significant increases in the dry-matter content of plant tops coincident with large accumulations of starch in the stems; (e) high concentrations of soluble carbohydrates in the fruits.

UNIVERSITY OF ALBERTA

THE CARBOHYDRATE-NITROGEN RELATIONSHIP IN TOMATO PLANTS, AS INFLUENCED BY SUCROSE AND UREA FOLIAGE SPRAYS

A THESIS

submitted to the School of Graduate Studies

in partial fulfilment of the requirements for the degree

of Master of Science

Faculty of Agriculture

Department of Plant Science

by

Donald A. Shaw

EDMONTON, ALBERTA

April, 1953

Table of Contents

Table of Contents (cont'd)

Table of Contents (cont'd)

INTRODUCTION

With the advent of economic processes for commercial production of the nitrogen carrying organic chemical urea, considerable interest has arisen concerning its usefulness as a fertilizer for crop plants. While most of the investigations in this respect have been concerned with the efficiency with which urea is utilized by plants when applied to the soil, limited experiments have been carried out with urea applied as a spray to plant leaves. Foliar application of certain minor elements, such as iron and boron, has proved practicable in certain areas where soil conditions cause these elements to be quickly tied up in forms unavailable to the plant, when they are applied to the soil.

Some rather extravagant claims have been made regarding the value of urea foliage sprays as a means of feeding nitrogen to crop plants, particularly by certain commercial firms. Some of these claims are largely unsupported by adequate experimental investigations or data.

The chief advantage of urea foliage sprays would appear to be that of maintaining a more precise control of the level of nitrogen in the plant at critical periods during its vegetative and/or reproductive development, in comparison with the usual methods of soil application. This advantage is predicated on the assumptions that the urea can be absorbed by leaves, and utilized by the plant for growth after absorption has occurred.

This project was initiated in an effort to obtain more basic information on the effects of urea foliage sprays, particularly in regard to their effect on the carbohydrate-nitrogen relationship, in the tomato plant.

LITERATURE REVIEW

Rates of Spray Application

A review of the literature (1, 2, 16, 18, 19, 23, 26, 31, 43, 58) reporting the use of urea foliage sprays indicates that for most species of plants spray concentrations much greater than 5 lbs. urea/100 gallons of water (approximately 0.1 Molar) are likely to cause leaf-burning. Certain species, as reported by Flower Grower (1) tolerate somewhat higher concentrations. The report states that 10, 15 and 20 lbs. urea/100 gallons of spray have been used on snap beans, citrus fruit trees and potatoes, respectively, without injurious burning occurring. No injury to tomatoes was reported where urea was used at the 5 gal. urea per 100 gal. water concentration. This statement does not agree with the observation made by Emmert and Klinker (16) that the same spray concentration used on tomatoes caused leaf-burn, especially during short winter days in Kentucky, when the rate of carbohydrate synthesis is low. Recent experiments by Emmert and co-workers (14) confirm their observation made in the preliminary trials.

Response of Plants to Urea Sprays

A number of workers (18, 23, 26, 43) have observed increased density of leaf color, following application of urea sprays to apples, cherries, navel oranges, roses and chrysanthemums. This increase was usually observed at 10-15 days after the spray treatment, and was most conspicuous where plants were previously deficient in nitrogen. Jones and Parker (26), and Hamilton et al (23) report that small differences in total leaf nitrogen due to urea spray treatment could be correlated with relatively large increases in the depth of green color of the foliage. Hamilton and co-workers observed no effect of urea sprays on fruit color in apples or cherries. Fisher and Skodvin (19) compared the effects of soil and foliage applications of urea to apple trees. They observed that urea sprays applied before midsummer resulted in slightly better fruit color than was obtained from an equivalent soil application. Midsummer sprays tended to increase fruit size, but markedly decreased color of the ripe fruits. In other experiments, Fisher and Cook (18) could observe no differences between soil and foliage application of urea, so far as the effect on fruit color was concerned. Weinberger et al (58) observed no effect of urea sprays on foliage color, fruit color, time of fruit ripening, or amount of terminal growth made in peach trees.

A favorable effect of urea sprays on vegetative growth in nitrogen-starved navel orange trees was noted by

Jones and Parker (26), and in roses and chrysanthemums by Pirone (43).

MacVicar and Gibson (29, 30) found urea sprays as effective as soil applications of $NaNO_3$ in increasing seed yields of orchard grasses. They observed that yield increases obtained where urea spray was applied may have been influenced by root absorption of excess spray which fell to the ground.

In recent experiments conducted on a soil naturally low in nitrogen, Emmert (14) has compared the effects of soil applied NH_4NO_3 and urea foliage sprays on lima bean yields. Yields for both treatments were highly significant over check yields, the soil application of nitrogen giving slightly the highest yield.

<u>Response of Plants to Sucrose and Urea-Sucrose Sprays</u>

In experiments utilizing young tomato plants, Went and Carter (59) compared growth rates of control and sucrose-sprayed plants under both ordinary greenhouse and controlled conditions of light and temperature. They concluded that beneficial effects of sucrose sprays on growth are to be expected when temperatures (especially the phototemperatures) are high and light intensities are low. This set of conditions would approximate those of a well-heated greenhouse under winter conditions in northerly latitudes.

In preliminary tests, Emmert and Klinker (16) found that increased levels of soluble carbohydrates were present in leaves and fruits of tomato plants following use of sucrose sprays. Fruits from sprayed plants were especially sweet and of good flavor and quality. In the same report it was stated that equi-molar additions of sucrose to urea sprays prevented leaf-burning normally associated with use of urea alone in spray. The protective action of sucrose was evident at combined spray concentrations as high as 1.0 Molar, the highest concentration tested.

In a more recent experiment utilizing Valiant tomatoes in a field test, Emmert (14) found sucrose sprays to result in significant increases in early yields. When urea was included, early yields were depressed. No significant differences were present in total yields. Much similar results were obtained in tests with Irish Cobbler and Sequoia potatoes. The results with tomatoes were taken by Emmert as indicative of the value of sucrose sprays in increasing plant carbohydrates during the cool shorter days early in the growing season, whereas they were ineffective during the warm longer days later on, when conditions favored high daily rates of photosynthesis. Plants were also found to make more efficient use of nitrogen applied as urea foliar spray, compared with similar amounts of nitrogen soil applied as nitrate.

Work carried out recently with tomatoes in field tests by Montelaro _et al_ (35) is not in agreement with

Emmert's conclusions as to the efficiency with which urea spray nitrogen is utilized. When compared with side-dressings of nitrate, comparable nitrogen applications as urea spray did not significantly increase or decrease earliness of maturity, total weight or number of fruits harvested. In the early stages of growth, tomato plants were found to respond more slowly to urea foliage sprays than to nitrogen applied to the soil at planting time.

The observation by Went and Carter (59) that sucrose sprays applied to young unhardened tomato transplants prior to moving enabled them better to withstand environmental stresses has recently been confirmed by the experiments of Smith and Zink (47). They found that when plants were thoroughly hardened there were no appreciable beneficial effects of "pre-transplanting" sucrose sprays. Unhardened plants showed lower mortality rates and less evidence of shock due to transplanting when they received a sucrose spray prior to moving. Transplants pulled and stripped of all lateral roots and stored in the dark for 96 hours at 68° F. showed little or no regeneration of lateral roots except where sucrose sprays had been applied previous to pulling.

The Time and Rate of Urea and Sucrose Absorption by Leaves

Most of the information on urea absorption is rather vague, evidence as to when absorption actually occurs

being indirect in most instances. Some workers (23, 26) have noted increased intensity of leaf color in from 10 - 20 days after spray was applied, more particularly in tests where an actual nitrogen deficiency existed. Presumably, absorption occurred within a somewhat shorter interval. Flower Grower (1) states that urea is largely absorbed by leaves within a few hours after spray application, but no reference is made to experimental results supporting the statement.

Higher total leaf nitrogen (23, 26) has been observed for periods ranging from 2 - 6 months after urea sprays had been applied, in comparison to check nitrogen levels, where apple and orange trees were the experimental material.

In preliminary tests, Emmert and Klinker (16) found higher levels of soluble leaf nitrogen when tomato plants had received urea spray one or two days previous to testing. Their statement as to time of testing is r ather ambiguous.

Cook and Boynton (8) in studies reported on while this investigation was underway, found urea to be absorbed very rapidly by McIntosh apple leaves, absorption beginning immediately following spray application. Approximately 12 - 80% of applied urea was absorbed in from 2 - 72 hours, the rate and total absorption being dependent on the influence of a number of factors. Both leaf surfaces absorbed urea, the lower most rapidly. Young leaves absorbed urea more rapidly than old, and differences in rates of absorption for high and low nitrogen leaves were highly significant, absorp-

tion being more rapid in the former instance. Differences in leaf levels of carbohydrates had no appreciable effect on the rate of absorption. Sucrose additions to the urea spray slowed down the rate of absorption, but did not decrease appreciably the total amount of urea absorbed. Addition of wetting agents almost doubled the rate of absorption, while the effect of spray pH was variable. The rate of absorption was generally highest around pH 5.6 and progressively lower at pH 8.0 and 7.2. Limited temperature and humidity tests indicated that when temperature and relative humidity combined to decrease the vapor pressure gradient between the spray droplets and the atmosphere, greater rates of absorption could be expected.

In relation to sucrose absorption, Went and Carter (59) obtained growth responses to sucrose sprays applied to tomato plants held in a dark-room within 6 days of spray application, which suggests that appreciable absorption occurred prior to the 6-day interval. Results obtained by Smith and Zink (47) suggest that absorption plus utilization of sucrose from sprayed sugar solutions takes place in young tomato plants within four days of spray application. Emmert and Klinker (16) apparently obtained evidence of sucrose absorption by tomato leaves from spray in from 1 - 2 days after spray. Their data are insufficient to permit any real evaluation as to the time or rate of sucrose absorption.

tion being more rapid in the former treatment. Differences in leaf content of phosphorus and potassium were also [illegible] in the various N-treatments. Increased nitrogen [illegible], on the other hand decreased leaf phosphorus, [illegible] [illegible], the [illegible]. [illegible] [illegible] [illegible] [illegible] 1.0 and 1.5. [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] be [illegible].

In addition to nitrogen, phosphorus, potassium and [illegible] Dugger (35) [illegible] [illegible] of [illegible] plants [illegible] [illegible] applications, [illegible] [illegible] [illegible] Aldi (47) [illegible] [illegible] [illegible] [illegible] [illegible] (16) [illegible] tomato leaves [illegible]. These data [illegible] to the [illegible] of [illegible].

The Absorption Pathway

In 1948, Roberts et al (45) showed that in the McIntosh apple leaf the cuticle is present as numerous discontinuous plate-like layers interspersed with pectinaceous material, the latter substance in all probability forming the indirect but continuous absorption pathway for spray materials to cells of the epidermis and/or vein extensions. That entry of spray materials is indeed possible by such a pathway has been shown by Cook and Boynton (8), as well as Rodney (46). The presence of stomata on upper and/or lower leaf surfaces may facilitate absorption somewhat. The greater rates of absorption by the lower leaf surface of apple leaves (which contain all the stomata) noted by Rodney, and also by Cook and Boynton, may, of course, be due in part to presence of a thinner cuticle on the lower leaf surface, as well as to the proportionately greater number of stomata thereon.

Went and Carter (59) found the lower leaf surface of tomato plants to be more permeable to sucrose than the upper surface. However, sucrose was found to enter the leaf as effectively with the stomata apparently closed as when they were open.

Physiological and Biochemical Considerations in Relation to Carbohydrate and Nitrogen Nutrition in Plants

Plant Responses to Internal Excesses and Deficiencies of Carbohydrate and Nitrogen

The growth responses made by the tomato plant under the various conditions producing internal excesses and deficiencies of carbohydrate and nitrogen are well known, chiefly as a result of the detailed studies of Kraus and Kraybill (27) and Nightingale _et al_ (38, 39).

Nightingale (36) has summed up very briefly the factors basic to plant response: "Excessive supply and absorption of nitrogen (especially as nitrate) will be followed by reduction and synthesis of organic nitrogen; if carried to excess, then carbohydrates (necessary for the reduction and synthesis) will naturally be depleted. With such a deficiency there can scarcely develop strong mechanical elements, so succulent weak vegetation occurs. Failure of plants to fruit abundantly when no nitrate (or other usable form of nitrogen) is available is not due directly to high carbohydrate reserves, the latter being rather an expression of the plant's inability to make further growth because of the nitrogen deficiency. Under these conditions, however, cleavage and reutilization of elaborated nitrogen in new growth may go on slowly unless carbohydrates are depleted by low light conditions, shading or manipulation of other factors vital to photosynthesis."

The Fate of Absorbed Sucrose

The evidence for sucrose absorption by plant leaves has already been discussed under a previous heading. Sucrose has long been considered as one of the earlier products of photosynthesis, and results of recent refined tracer studies, discussed by Bonner (5), confirm the idea. Sucrose absorbed from foliar sprays should normally supplement the internal sucrose supply of the plant, being available as an energy source for respiration as well as a source of organic carbon for incorporation in structural polysaccharides, protein, starch reserves, etc.

The Fate of Absorbed Urea

Nightingale (36) in his extensive review on the nitrogen nutrition of plants reports that Klein and Taubock demonstrate the presence of free urea in immature fruits and seeds of numerous plants; with maturation it could no longer be detected. The same workers showed that urea is present normally in some green plants, as well as the enzyme catalyzing its hydrolysis to carbon dioxide and water. They believed urea to be in many respects similar in function to the plant amides asparagine and glutamine, whose role as a plant mechanism for ammonia detoxification and provision of reserve nitrogen has been fairly well established by the extensive investigations of Prianischnikow, and others, as reviewed by Chibnall (7) and Vickery et al (54, 55).

McKee (32) considers that urea might contribute to synthesis of arginine among all the amino acids. Reifer and Melville (44) suggest, on the basis of extensive experimentation with rye-grass, that urea may be in some plants, at least, a raw material for biological synthesis within the plant, or may function as a third plant amide, the latter idea being in agreement with the conclusions of Klein and Taubock, previously mentioned.

The logical point of entry for urea into the nitrogen economy of the plant would appear to be via ammonia following enzymatic hydrolysis within the plant by urease. The ammonia subsequently would be utilized in amino acid and protein or amide synthesis, depending on the immediate requirements of the plant and according to the generalized scheme of the course of organic nutrition proposed by Gregory and Sen (22). This scheme appears adequately to represent the facts so far as they are known, and most of the results of many workers including Chibnall (7), Eckerson (10), and Vickery _et al_ (54, 55) are in general agreement with such a scheme.

Recent work by Yemm (60) suggests that glutamine occupies a key metabolic role in the interconversion of amino acids in barley, as well as forming a substantial portion of the nitrogen moving to meristematic or other centers of protein synthesis. Since glutamine is the major amide of tomatoes (53), synthesis of this compound within the plant from the

nitrogen of urea might still leave such nitrogen in a metabolically active state.

Sumner and Somers (49) suggest that plants may use the enzyme urease to destroy urea, so preventing its accumulation within the plant (presumably as an end-product of nitrogen metabolism, though this was not stated). The ammonia coming from hydrolysis would then, of course, be re-utilized by the plant in new amino acid, protein and/or amide synthesis, as has already been discussed.

Though no direct statement was encountered in the literature to confirm the presence of urease in tomato plants, its demonstrated presence in numerous other plant species would suggest that urea may, in fact, enter the normal nitrogen economy of the tomato plant following its enzymatic hydrolysis to ammonia.

Mineral Nutrition in Relation to Carbohydrate and Nitrogen Nutrition in the Plant

The effects of mineral nutrition on carbohydrate and nitrogen relationships of plants have been widely investigated, as well as the effects of nitrogen source. Steinberg, in his review of this subject as edited by Truog (51), has summarized the results of a number of these studies in a way which seems to reflect the conclusions of the majority of workers:

"Mineral deficiencies in plants appear to lead to a relative accumulation of amino acids and reducing sugars. Protein may or may not decrease depending on the extent and duration of deficiencies. Accumulation of nitrates appears to be a result of diminished growth, except in the case of molybdenum. The alterations in proportions of nitrogen fractions lead to the assumption that all minerals participate directly or indirectly in nitrogen metabolism. Carbohydrates may temporarily accumulate during the early stages of deficiency. Evidence exists for a localization effect in that plant parts show a degree of parallelism between severity of visual and chemical symptoms. It appears useless to attempt to draw any connection between individual deficiencies and physiological responses in the plant, since protein metabolism is a basic reaction for all."

Because of the key (but largely undefined) role of potassium in plant nutrition, a fairly extensive review of the pertinent literature was made. Nightingale et al (39) in 1930, as a result of experiments with tomato, postulated a direct or indirect role of potassium in CO_2 assimilation, the initial stages of nitrate reduction, cell division, and synthesis of meristematic protein. Beckenbach et al (3) has suggested that potassium may be essential to the processes by which energy utilized in nitrogen metabolism is released from the simple sugars. Noggle (40) concluded that adequate potassium was necessary for protein synthesis, while Wall (57) working with tomatoes obtained results which led him to the

conclusion that protein synthesis from an elaborated form of nitrogen is checked by potassium deficiency. The latter view would appear generally to express best the opinion of a majority of workers. Phillips _et al_ (41, 42) have noted some of the responses of tomatoes to low and high levels of potassium and nitrogen, but postulated no specific role for potassium. Nightingale (36) observes that Prianischnikow found an abundance of potassium to be more essential in ammonium than in nitrate nutrition of sugar beets. Work on pineapples by Nightingale (37) confirms the finding of Prianischnikow. This effect presumably is somehow related to the more reduced form of nitrogen in the ammonium ion, as compared with the nitrate ion. Whether urea, also a reduced form of nitrogen might react similarly can only be speculated.

In relation to ammonium and urea nitrogen nutrition, there seems to be a certain parallelism in plant responses to high levels of both forms of nitrogen. In the case of high ammonium nutrition in corn, Viets _et al_ (56) observed the toxicity symptoms to be expressed in severe water deficit plus the appearance of necrotic areas on the leaves and leaf tips. Tiedjens (50) noted tomatoes to be retarded in growth, with breakdown of pith cells, plant foliage appearing greyish-green in color, as a result of very high rates of ammonium feeding. A necrotic "burning" of leaves often follows spray application of urea to plants, as has been recorded by Emmert and Klinker (16) and others. McKee (32)

in his review of work on nitrogen metabolism reports the following experimental results were obtained by Kultscher. He fed urea to Phaseolus vulgaris (an "amide" plant) and to Begonia spp. (an "acid" plant). The roots of both kinds took up urea readily and ammonia was formed in their tissues. In the Begonia, it was stored as the salt of an organic acid and later synthesized to protein; but the "amide" bean plant was severely damaged, because, he concluded, its protective mechanism was unable to deal with a sudden large excess of ammonia. The results of these workers seem to lend support to the idea that ammonium and urea nitrogen, being somewhat similar as to their state of reduction, probably enter the nitrogen economy of the plant by much the same pathway, inducing apparently similar plant responses as their concentration is increased or decreased.

The Influence of Environment on Carbohydrate Synthesis and Accumulation

Daily and seasonal fluctuations in the individual and combined levels of sugars and starch are undoubtedly related closely to daily and seasonal variations in such factors of the environment as light intensity, day length, temperature and humidity.

Studies such as those of Heinicke and Childers (24) and Heinicke and Hoffman (25) show that most high daily rates of photosynthesis and carbohydrate accumulation are

associated with relatively high light intensities, medium to long photoperiod (which, of course, rises to a peak in midsummer and decreases as fall approaches), along with optimum conditions of temperature and humidity. In the case of intermediate daily rates, the relationship with light intensity tends commonly to be complicated by the ascendancy, in varying degree, of other factors including temperature, humidity and transpiration rate, as they affect the photosynthetic process. High vapor pressure deficits favor increased transpiration and subsequent internal water deficits in the plant which may result in reduced rates of photosynthesis. Variations in temperature, within the normal limits for active photosynthesis of about 10 - 35° C. appear to affect respiratory rates more than those of photosynthesis. Increases in temperature are associated with increased respiratory rates so that the net accumulation of carbohydrates is less at high than at low temperatures.

1951 FIELD EXPERIMENT

A preliminary field experiment was initiated in the spring of 1951, with the following objectives in mind:

(1) To obtain, if possible, confirmation of the effects of urea and sucrose, alone or in a combined spray, as observed by Emmert and Klinker in Kentucky.

(2) To gain familiarity with the technique to be used in testing for soluble nitrogen and carbohydrates.

(3) To obtain some information as to the effects of these sprays on the C/N ratio in tomato plants.

Material and Methods

The land used for the experiment is a black clay loam, and had been part of a plum orchard for some years prior to 1950. Due to severe infestation with couch grass, the trees were removed and the orchard plowed in the spring of 1950. Successive cultivations plus a favorably dry summer permitted a good kill of the couch grass. Part of this area which appeared free of couch grass in the late spring of 1951 was used as the experimental plot.

Seed of Early Alberta tomato, a locally bred and adapted variety (parentage, Bounty x Golden Bison) was planted in the greenhouse on April 11. Seedlings were pricked

out into flats May 9 and were transplanted to the experimental plot at 3' x 3' spacing on June 9. Soil moisture was adequate at this time and remained so during most of the growing season. Good vegetative growth was secured following transplanting, although the season was generally cool as well as moist.

The experimental plot consisted of three blocks of 30 plants each. Spray treatments applied were as follows:

Treatment No.	Spray Treatment
1	Check
2	0.1 M. urea
3	0.5 M. urea
4	1.0 M. urea
5	0.1 M. sucrose
6	0.5 M. sucrose
7	1.0 M. sucrose
8	0.1 M. (urea + sucrose)
9	0.5 M. (urea + sucrose)
10	1.0 M. (urea + sucrose)

Treatment numbers indicate the position of each treatment in the experimental plot, the layout of which is given in Appendix A-I.

Block I received all 3 spray applications made, while Block II received the second and third sprays, and Block III received only the final spray application.

The first spray was applied on July 28, and the second and third sprays at 2-week intervals thereafter, on August 12 and August 25, respectively.

Leaf samples were taken one week and 3 weeks after each spray application and analyzed for soluble carbohydrate and nitrogen*.

Method of Taking Leaf Samples

Only healthy, relatively mature leaves of approximately the same physiological age, and showing no signs of yellowing or abscission, were selected from the centre plant of each 3-plant treatment unit for analysis purposes. In practice, this meant that samples were taken from the lower, but not the lowest, portion of the plant. In the case of the "urea only" treatments, leaf samples usually contained a percentage of brown, dry, necrotic tissue, due to leaf-burning which had occurred. Leaves were not eliminated from the sample on account of this necrotic tissue, but some attempt was made to include only an amount of necrotic tissue which represented the condition generally of the leaves on the treated plant. Sufficient leaf material for a 1-gram final sample was collected on the day of analysis, usually between 9 a.m. 10:30 a.m. In one or two cases only, samples were taken later in the day, but never after 2:30 p.m. Leaf samples were

---

* The first analysis was not made because the technique of analysis was not yet completely acquired.

placed in labelled envelopes and taken to the laboratory immediately after collection, for weighing and analysis, which was carried out without delay.

Method of Weighing and Extraction

Essentially the method used was that of Emmert (12, 13): a 1-gram sample of the fresh leaf material was weighed accurately to within 1 mg. on an analytical balance. The sample was then transferred to a mortar, a few tenths of a gram of finely powdered charcoal added to decolorize the extract, and an initial 5 ml. aliquot of 2% acetic acid solution was introduced by pipette. The sample was thoroughly macerated and a further 5 ml. of 2% acetic acid solution was added during the grinding process. The insoluble residue and the charcoal were removed by filtering through Whatman #1 filter paper. The clear extract was received in clean 20 ml. testtubes, which were then stoppered and set aside until all the day's extractions were completed. Immediately following the final extraction for the day, the analyses were carried out.

Method of Analysis

1. Soluble Carbohydrate Estimation

The method used was that of Emmert and Waltman (15). One ml. of the leaf extract was placed in a 30 ml.

test tube previously permanently calibrated at the 25 ml. level, using a 1 ml. small bore pipette. Then 2 ml. of fuming H_2SO_4 (20% - 30% SO_3) was added fairly rapidly, with agitation of the test tube. The resulting solution was allowed to stand 10 - 15 minutes, after which it was made up to 25 ml. with 50% (by volume) C.P. H_2SO_4. The tube was then stoppered with a rubber cork and agitated gently to distribute the colored fraction uniformly throughout the solution. This latter step was found necessary if accurate results were to be obtained. The colored solution was allowed to stand at least four hours to ensure that all bubbles were dispersed from the solution, after which photometric determination was carried out, with a Fisher A.C. Model Electrophotometer. The photometer dial reading obtained by comparison with a blank was used in conjunction with a calibration curve* to obtain the concentration of soluble carbon present in parts per million. The value obtained multiplied by 10 gave the final result in parts per million of soluble carbon present in the fresh leaf tissue. The test, according to Emmert and Waltman, gives a good estimate of total soluble carbohydrates present, but does include such soluble carbon as may be present in soluble amino or organic acids.

---

* For details of the photometer calibration curve, see Appendix E-I.

2. Soluble Nitrogen Estimation

The rapid soluble nitrogen test described by Emmert (12, 13) was used. With a small bore 1 ml. graduated pipette, 0.5 ml. of the leaf extract was placed in a 40 ml. test tube previously permanently calibrated at the 30 ml. level. A small excess of $NaClO_3$ was added. The amount necessary varies with the amount of carbohydrate present in the extract. A crystal about the size of a grain of wheat was usually sufficient (approx. 0.05 gram). Then 1 ml. of fuming H_2SO_4 was added rapidly enough to cause boiling, the test tube was agitated and the evolved chlorine fumes were blown out by means of a piece of bent glass tubing, until the solution cleared. As soon as the solution was cool to the hand, 1 ml. of phenol-di-sulfonic acid was added, and the solution agitated to ensure complete reaction. After ½ - 1 minute 12 - 15 ml. distilled H_2O were added, then 40% NaOH until the solution was definitely basic to litmus, and the maximum yellow color had developed. The yellow solution was made to 30 cc. with distilled H_2O, mixed thoroughly, and the photometric determination completed by comparison with a similarly prepared blank. The photometer reading was converted into parts per million soluble nitrogen by means of the previously prepared calibration curve*. This value multiplied by 20 gave the concentration of soluble nitrogen present in the fresh leaf tissue.

---

* See Appendix E-II.

According to Emmert, this test estimates accurately only nitrogen of nitrate, amino compounds and urea.

Using the above procedures, it was usually possible to complete carbon and nitrogen analysis on 10 samples in 1 day, leaving glassware washed and ready for the next day, providing no unforeseen difficulties were encountered.

Results

1. Visual Effects of Sprays

In general, observations made following the spray applications confirmed those made by Emmert and Klinker in their Kentucky tests. Urea alone caused slight to rather severe burning of the leaves which was evident in from 1 - 3 days after spraying. The degree of burning increased progressively with the spray concentrations used and to a lesser extent with the number of sprays applied. At the 1.0 molar level, the general effect of individual spray applications was to kill from 5% - 25% of the leaf blade tissue, with about one-third of the leaves of individual plants showing the maximum percentage of burning. Progressively less leaf-injury was observed as the urea concentration decreased. Injury for any single spray application at the 0.1 molar level was slight. Total leaf injury in some cases appeared greater when the weather on the spray date and the succeeding day or so was cloudy.

The leaf-burn was predominantly of the marginal type, with the centre and base of the lamina remaining unaffected. Burning was characterized by a change from the normal green tissue color through a greyish-green stage which was rapidly replaced by a brown scorched appearance as the tissue died and became dry and brittle.

The inclusion of sucrose with urea prevented burning almost completely at the 0.1 molar and 0.5 molar levels, while a slight amount of burning occurred on some leaves of individual plants at the 1.0 molar level. Total injury to plants, at this concentration, was estimated to involve not more than 1% - 3% of the total leaf area .

Plants receiving all concentrations of sucrose spray appeared quite normal.

2. Results of Analyses

The complete analytical data for the experiment are given in Appendices A-II and A-III. To evaluate the influence of successive sprays and of the spray test-date interval, the data were classified for that purpose; results for the three spray concentrations within each treatment being summated and averaged to give mean values for each treatment in each of the two classifications made.

Table 1 shows the effects of successive applications of spray, irrespective of time of testing. An examination of Table 1 shows that the soluble carbon level of check

Table 1. Mean soluble carbon and nitrogen levels of tomato leaves receiving 1, 2 and 3 urea spray applications, irrespective of spray concentration or time of testing employed, expressed as p.p.m. of fresh leaf sample.

	Number of Sprays												
	1*				2*				3*				
	C		N		C		N		C		N		General Means
Treatment	Mean	Over check	Mean	Over check	Mean	Over check	Mean	Over check	Mean	Over check	Mean	Over check	C/N
Check	2871	--	120	--	2675	--	131	--	2175	--	145	--	2574/132
Urea	3817	946	111	-9.0	3353	678	182	51	3019	844	191	46	3396/165
Sucrose	3147	276	129	9.0	3452	777	173	42	3217	1042	166	21	3272/154
(U + S)	4905	2034	64	-56	4806	2131	211	80	3042	867	281	135	4251/187

* 1 Spray data - check values are means of 5 analyses; others of 15 analyses.

2 Spray data - check values are means of 4 analyses; others of 12 analyses.

3 Spray data - check values are means of 2 analyses; others of 6 analyses.

plant leaves ranged generally from 2200 p.p.m. to 2900 p.p.m. during the course of the experiment, with a mean level of 2574 p.p.m. A trend towards lower levels can be observed in the check data, noted from left to right across the Table. The soluble nitrogen data show a complementary reverse trend which suggests that together the trends may be a reflection of lower daily rates of photosynthesis as the season advanced, with consequently reduced rates of nitrogen utilization.

The most striking effect of any of the three treatments imposed is that of urea. It apparently stimulated large increases in the soluble carbon content of the leaves, and so, presumably, of soluble carbohydrates. The effect of successive urea sprays was to maintain, or restimulate, higher levels of soluble carbon than occurred in the check plant leaves. Concurrently, successive sprays appeared to have increased the leaf content of soluble nitrogen to some extent.

The sucrose treatment also appeared to cause an increase in the soluble carbon level, which became greater with the number of sprays applied. Concurrently, the soluble nitrogen level showed some increase over checks, which may or may not have significance. The small increase in soluble carbon of 276 p.p.m. over check in this treatment at the single spray level is in striking contrast with the comparable value of 946 p.p.m. where urea was applied. If sucrose is absorbed by the leaves, such absorption appears to occur rather slowly.

The progressively greater increases over checks as the number of sprays applied increases also seems to offer support to the suggestion.

The combined urea-sucrose treatment stimulated increases in the leaf levels of soluble carbon, overshadowing those occurring in either the urea or sucrose treatments. Increases over checks are very large at the one and two-spray levels especially, while a sharp drop in the soluble carbon level occurred at the 3-spray level, for no readily apparent reason. The soluble nitrogen, at the 1-spray level was greatly depressed in comparison with checks. This depressing effect is also present at the 1-spray level of the urea treatment, but is relatively less significant. It would appear that urea, rather than sucrose, is the active factor involved in this depression. At the two and three-spray levels, the soluble nitrogen showed progressively greater increases over checks in the combined spray treatment. The large increase over check, at the 3-spray level, of 135 p.p.m. is complemented by the sharp drop previously noted in the soluble carbon level. Table 2 illustrates the effect of treatments and successive sprays on the C/N ratio. The very high C/N ratios for the urea and urea-sucrose treatments at the 1-spray level are noteworthy, especially as they are partially accounted for by depressions in soluble nitrogen.

Table 2. Approximate soluble C/N ratios of tomato leaves as derived from data of Table 1.

	Number of Sprays			
Treatment	1	2	3	Mean C/N Ratio per treatment
Check	24/1	20/1	15/1	20/1
Urea	34/1	18/1	16/1	23/1
Sucrose	24/1	20/1	19/1	21/1
(U + S)	77/1	23/1	11/1	37/1

Table 3 shows subdivision of the data according to the spray test-date interval. The data suggest that the urea and urea-sucrose treatments resulted in higher levels of soluble nitrogen than occurred in either the check or sucrose treatment. In general, this subdivision of the data reflects general effects of the treatments as previously noted, and does not suggest that either test date was preferable insofar as detecting variations in the carbon and nitrogen levels due to treatments is concerned.

Table 4 gives the C/N ratios derived from the data of Table 3. The high C/N ratios at the 3-week test date are a reflection of decreased levels of nitrogen rather than increased levels of carbon, as will be noted from Table 3.

Table 3. Mean soluble carbon and nitrogen levels of tomato leaves irrespective of concentration or number of sprays applied, as shown by tests made 1 week and 3 weeks following spray applications, expressed as p.p.m. of fresh leaf sample.

	Spray Test-date Interval								
	1 week*				3 weeks*				
	C		N		C		N		General means
Treatment	Mean	Over checks	Mean	Over checks	Mean	Over checks	Mean	Over checks	C/N
Check	2933	--	182	--	2214	--	83	--	2574/132
Urea	3917	984	215	33	2871	657	108	25	3394/165
Sucrose	3579	646	209	28	2965	751	102	20	3272/154
(U + S)	4657	1724	243	62	3845	1631	127	44	4251/187

* 1 week data - check values are means of 5 analyses; others of 15 analyses.

3 week data - check values are means of 6 analyses; others of 18 analyses.

Table 4. Approximate soluble C/N ratios of tomato leaves as derived from data of Table 3.

	Spray Test-date Interval		
Treatment	1 week	3 weeks	Mean C/N Ratio per treatment
Check	16/1	27/1	22/1
Urea	18/1	27/1	23/1
Sucrose	17/1	29/1	23/1
(U + S)	19/1	30/1	25/1

The urea treatment resulted in slight increases in soluble nitrogen at the 1-week test date, and very large increases in soluble carbon, which are reflected in an increased C/N ratio. At the 3-week date, increases in carbon and nitrogen were such that little change occurred in the C/N ratio.

The sucrose treatment resulted in an increased C/N ratio at both test dates, the increase being greatest at the 3-week date.

The urea-sucrose treatment showed increases in both carbon and nitrogen at both test dates, such that a large increase in the C/N ratio occurred, due to very large increases in soluble carbon.

Discussion

The effects of urea on the leaf content of soluble carbohydrates, as shown by the test used, appear rather complex. Urea, alone or in combination with sucrose, apparently stimulated larger increases in the soluble carbohydrate level of leaves than did sucrose alone. The effect was most prominent at the 1-week test date which suggests that the greatest effect of urea on the soluble carbohydrate level of leaves may occur prior to one week after spray application.

The sucrose treatment appears to have caused some increases in soluble leaf carbohydrates. The results indicate a progressively greater influence with the number of sprays applied and with increase in the spray test-date interval. These trends suggest that absorption of sucrose may occur rather slowly, as compared with urea.

It must be stated that the effects of sucrose, as shown by the data presented, and urea to a lesser extent, may have been influenced by spray residues remaining on the leaf samples. Some precipitation occurred during most of the spray test-date intervals, but evidence of spray residue was observed on very few of the samples taken for analysis. It was considered best to complete the tests on a uniform basis, once they had been started, and so none of the leaf samples was washed. In any subsequent work, this source of possible error should be eliminated by washing the leaf samples prior to

analysis. Washing in itself may, of course, introduce a small error, which should, however, be a relatively uniform one.

From a study of the results obtained, some speculation as to the action of urea can be made. Absorption of urea by leaves should cause at least a temporary rise in soluble leaf nitrogen. It is thought that this increased level of nitrogen may stimulate a mobilization of starch reserves to soluble carbohydrates. Such a response was observed by Kraus and Kraybill (27) following application of nitrogen to nitrogen-deficient tomato plants. These carbohydrates presumably may be utilized in the conversion of the absorbed nitrogen to amino acids and/or protein.

Should urea on absorption be hydrolyzed to NH_3 and CO_2 through the action of urease, which is known to be present in many species of plants (36), then either amino acid or amide synthesis might occur. No literature yet reviewed confirms the presence or absence of urease in tomato plants. Amide synthesis (5, 22, 55) presumably would bind the absorbed nitrogen in a non-toxic form, from which it may or may not later be activated.

If the nitrogen of urea is converted to amide, chiefly glutamine in the tomato (53), a depressed soluble nitrogen level would be obtained as amide synthesis progressed, due

to the fact that the test used does not include nitrogen of either NH_3 or amides. Such a depression was observed at the 1-spray level (Table 1) and the depression was greater where sucrose was included along with urea. It is speculated that the maximum depression in the soluble nitrogen level occurred prior to the 1-week test date. The design of this experiment does not permit any real evaluation of such a hypothesis, due to the overlapping effect of number of sprays applied with the spray test-date intervals, as well as the fact that the 1-week test date was the earliest employed.

A sharp drop in the soluble carbon level occurred in the urea-sucrose treatment at the 3-spray level. This drop was complemented by a rise in the soluble nitrogen level. If the nitrogen from absorbed urea is partially converted to amide, due to lack of a sufficiently high level of soluble carbohydrates in the leaf for amino acid synthesis, then a later absorption of sucrose and/or mobilization of soluble carbohydrate from starch reserves within the plant may then permit utilization of the amide nitrogen in amino acid and protein synthesis. Such a mechanism would agree in general with results obtained by Prianischnikow as reviewed by Vickery <u>et al</u> (55), Gregory and Sen (22), Blackman (4), and Chibnall (7).

If urea is hydrolyzed within the leaves to NH_3 and CO_2, a rise in the leaf level of CO_2 may be expected. This rise might be conducive to higher rates of photosynthesis than could otherwise be expected during periods of the day when at-

mospheric uptake of CO_2 is often a factor limiting photosynthesis. It seems doubtful that the amount of CO_2 which could be made available by hydrolysis of the urea would be of much significance in this regard.

The C/N ratios obtained are, of course, a reflection chiefly of the soluble carbohydrate and soluble nitrogen levels in the leaves, rather than the overall C/N ratio. Both the urea and urea-sucrose treatments resulted in early increases in the C/N ratio, which increases were primarily due to very large increases in the soluble carbon level, plus a small decrease in the soluble nitrogen level. Sucrose appeared to exert its effect later than urea. Increases in the C/N ratio associated with the sucrose treatment were due largely to increases in the level of soluble carbon, while the soluble nitrogen level showed slight, variable increases which probably have no significance. The effect of the urea-sucrose treatment at the 1-spray level is striking, where the C/N ratio was 77:1, compared with a check ratio of 24:1.

Visual observations made during the course of the experiment confirm those made by Emmert and Klinker (16). Urea applied alone caused marginal or tip leaf-burning, evident 2 - 3 days after spray was applied, which became progressively greater with higher spray concentrations, as well as with the number of sprays applied. Sucrose combined with urea at an equi-molar concentration was effective in preventing any appreciable leaf-burn, even at the 1.0 molar level.

The general levels of soluble leaf carbon obtained in this experiment are at variance with data given by Emmert and Klinker (16). Their data show soluble leaf carbon in check plants as ranging around 28 - 35 p.p.m. These values are of the order of 450 p.p.m. lower than the lowest value obtained in this experiment. The lowest value obtained for any check plant leaves was 800 p.p.m., while the overall mean level for check plant leaves was close to 2600 p.p.m. Emmert's and Klinker's experiment was carried out in Kentucky in the greenhouse under winter conditions, which may, in part, account for the divergence in experimental results. No data were given on the soluble nitrogen levels in the above check plants. In another test reported on in the same bulletin, check data were given for both soluble carbon and nitrogen. Soluble carbon ranged from 8 - 24 p.p.m., and soluble nitrogen from 714 - 1247 p.p.m. It was implied, but not specifically stated, that leaf samples were the basis of the analytical data. From a few petiole tests made at the University of Alberta, it is thought that the data actually were based on petiole analyses. In an effort to discover if serious error had been involved, due either to method of analysis or the technique used, some of the data presented by Kraus and Kraybill (27) were compared with the data of this experiment. Values for nitrate nitrogen, sucrose and free-reducing substances from their data, based on fresh weight of leaf sample, were converted to p.p.m. soluble nitrogen and carbon, and the values for sucrose and free-reducing substances were summed.

Table 5 shows the adapted data from the Kraus and Kraybill report.

Table 5. Concentrations of soluble nitrogen and carbon in various series of tomato plant leaves, expressed as p.p.m. of fresh leaf sample. (Adapted from Kraus and Kraybill.)

		Portion of Plant					
		Upper leaves			Lower Leaves		
Series		C	N	C/N	C	N	C/N
G	Sept. 28 - clear	1276	124	10.3/1	730	187	3.9/1
O	Apr. 16) partly	3395	0		2807	0	
P	")	1842	7.9	230/1	1454	27.2	54/1
Q	") cloudy	769	73.5	10.4/1	360	167	2.2/1

G - vegetative, vigorous, yet somewhat fruitful.

O - non-vegetative, stems yellowed, leaves grey-green, second blossom clusters not setting fruit (N-deficient).

P - moderately vegetative, normally fruiting plants which received normal nitrogen and H_2O.

Q - Excessively vegetative, leaves and stems soft, drooping, blossoms excising and no fruit-setting. (Large amounts of nitrogen and H_2O applied.)

The analytical data from the series G leaves, in particular, correspond reasonably well with the data of this experiment for check plant leaves. Series O, P and Q plants were grown in the greenhouse and leaves taken for analysis the middle of April, and conditions were therefore approxi-

mately equivalent to those obtaining in the tests made by Emmert and Klinker, where tests were made in March on greenhouse-grown plants. The difference in latitude between the two locations would tend to favor lower photosynthetic activity in the Oregon experiments of Kraus and Kraybill, and presumably lower values for soluble carbohydrates as compared with the tests made by Emmert and Klinker. On the contrary, the data adapted from Kraus and Kraybill show a much closer correlation with the data of this experiment. The adapted data are, of course, not strictly comparable, due to the differences in methods of analysis, as well as the fact that Kraus and Kraybill determined only nitrate nitrogen.

The analytical data of Emmert and Klinker, whether from check cr treatment plants, show little correlation with the results of this experiment, which appears unaccountable, even if allowance be made for understandable variation which might arise between results from greenhouse and field work, or from geographical or seasonal variability between experiments.

Conclusions

1. Results of this experiment with tomato plants confirm those of Emmert and Klinker insofar as the type and degree of leaf-burning caused by urea foliage sprays of varying concentration is concerned.

2. Sucrose, applied in a combined spray with urea at equi-molar rates was effective in preventing appreciable leaf-burning, even at the 1.0 molar concentration, the highest used in the experiment, regardless of the number of spray applications made.

3. Urea applied alone in a foliage spray caused leaf-burning which was cumulative as the number of spray applications increased.

4. Urea applied alone or as a combined spray with sucrose, stimulated large increases in leaf levels of soluble carbon, and so presumably of soluble carbohydrates, as indicated by the tests made. Concurrently, decreased levels of soluble nitrogen were observed.

5. Sucrose stimulated increases in the level of soluble leaf carbon, which tended to be cumulative as the number of spray applications increased. Due to the technique used in sampling, these increases may have no significance.

6. Sucrose appears to be absorbed by tomato leaves at a slower rate than urea.

7. The experimental data suggest that the maximum stimulatory effect of urea spray may be exerted prior to the earliest (1 week) test date used in this experiment.

8. Experimental data of this experiment show little correlation with results presented by Emmert and Klinker, so far as the relative levels of soluble nitrogen and carbon in tomato leaves are concerned.

9. Data adapted from the experiments of Kraus and Kraybill, while not strictly comparable, show a closer relationship with the levels of soluble nitrogen and carbon obtained in this experiment than do the data of Emmert and Klinker.

10. Urea was more effective than sucrose in stimulating increases in the soluble C/N ratio in tomato plant leaves, which increases were chiefly associated with very high levels of soluble carbon.

1951 GREENHOUSE EXPERIMENT

Results obtained in the preliminary field experiment suggested that the peak rate of urea absorption by tomato leaves may have occurred prior to the earliest (1 week) test date following spray application which was used in the experiment. Presumably, if such is the case, the maximum stimulatory effect of urea on leaf levels of soluble nitrogen and carbon may also have occurred prior to the one-week test date. A greenhouse trial was initiated to obtain any information possible regarding the time at which maximum absorption of urea occurs.

Materials and Methods

Eight plants of Early Alberta tomato, established in 6" clay pots containing composted clay loam and sand in a 3:1 mixture, were used for the experiment. The plants were 15" - 18" in height and inclined toward vegetative growth, though one or two clusters of flower buds were showing on all plants when experimental spray treatments were applied. Spraying was done on December 26 at 2:00 p.m., with two replications in the case of each treatment. Spray treatments were as follows:

1. Check (no spray applied).
2. 0.5 M. urea.

3. 0.5 M. sucrose.
4. 0.5 M. (urea + sucrose).

Plant leaves were saturated with the spray mixture, and placed in a single north-south row on an east-side bench in the greenhouse at a height of approximately 3½ feet above floor level. The temperature ranged from 50° - 60° F. in this location during the course of the experiment. Due to the dull, cloudy weather prevalent in December, this location was considered to have the most uniform conditions available with regard to temperature and light. The plants received most of the available light from a west-south-westerly direction.

Prior to spray treatment, a few basal leaves which showed yellowing were removed from the plants. Remaining leaves were all a healthy medium green color. The leaf blades appeared rather thin, probably due to development under low light intensities and during very short daylight periods.

From December 27 to January 3, inclusive, leaf samples were taken at 9:00 am. (exception, January 3 - 2:00 p.m.) from each of the test plants and analyzed for soluble nitrogen and carbon. The analyses were carried out according to the methods used in the field experiment, except that: (1) successive daily samples were removed progressively from the base of the plants upward, in order to minimize to some extent differences in physiological age of the leaves; (2) each leaf

sample was washed thoroughly in clean, luke-warm distilled water and dried between layers of paper towelling prior to weighing, to remove any urea or sucrose spray residues.

Negative or "trace" tests only for soluble carbon were obtained from samples analyzed during the first seven days. As a result, artificial light was applied to the plants in an effort to determine if the light conditions prevailing were responsible for the negative and low carbon tests obtained. Three 300 watt General Electric self-reflector type lamps were placed about one foot above the growing tips of the plants, which were regrouped into 2 rows of 4 plants each in order to secure a relatively uniform distribution of light to all plants. The lights were turned on at 5:00 p.m. January 2, and the final set of leaf samples taken at 2:00 p.m. January 3, when the plants had received a 21-hour period of artificial light.

Prior to, and during the course of, the experiment, the weather was dull and cloudy, with the exception of the afternoon of December 30 and the two succeeding days, which were relatively clear and sunny. Even on these days light conditions were poor, in comparison with summer conditions either in greenhouse or field.

Results and Discussion

The data from the soluble nitrogen and carbon tests are given in Tables 6 and 7.

Table 6. Levels of soluble nitrogen in tomato leaves during 8 days following spray application of urea, sucrose and urea plus sucrose, expressed as p.p.m. of fresh leaf sample.

	REPLICATES								
	I				II				
Day	Check	Urea	Sucrose	(U + S)	Check	Urea	Sucrose	(U + S)	Mean
1	1870	3102	1430	1870	1826	1716	1144	1452	1802
2	1518	2738	1760	1298	1485	3190	1474	1100	1819
3	902	2640	1078	1144	1650	2772	924	1485	1574
4	1364	2134	1430	770	660	1089	946	814	1151
5	1804	2156	1947	1188	1914	1782	1584	1232	1701
6	1243	1518	1584	1254	1672	1628	616	1254	1346
7	990	924	1474	946	968	1463	902	924	1074
8	627	726	836	858	957	968	1012	1100	886
Mean	1290	1991	1441	1166	1392	1826	1076	1170	

General treatment means - Check - 1341 Sucrose - 1258
Urea - 1909 (U + S) - 1168

Table 7. Levels of soluble carbon in tomato leaves during 8 days following spray application of urea, sucrose and urea plus sucrose, expressed as p.p.m. of fresh leaf sample, or as "trace" values.

	REPLICATES							
	I				II			
Day	Check	Urea	Sucrose	(U + S)	Check	Urea	Sucrose	(U + S)
1	0	0	0	0	0	0	0	0
2	0	Tr-	0	Tr-	0	0	0	0
3	Tr-	0	Tr-	Tr-	0	0	Tr-	0
4	0	0	0	Tr-	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	Tr-	0	Tr+	0	0	Tr+	Tr-
8	600	1700	750	1340	1600	1800	2120	Tr+

As was previously intimated, the soluble carbon tests were either negative or too low to obtain accurate photmetric readings, except on day 8, after artificial light had been applied. Positive indications of soluble carbon which were too low to be accurately measured were estimated as "trace-", "trace" or "trace +." The latter value was estimated as being about 150 - 200 p.p.m. soluble carbon based on weight of fresh leaf sample.

The effect of artificial light, as shown by the soluble carbon data of Table 7 is rather striking. With one

unaccountable exception, the soluble carbon level of all plants rose to 600 p.p.m. or more, in contrast with the negative or "trace" values for the first seven days under natural light conditions. In relation to time after spraying, most of the "trace" tests were obtained on the second or third day. "Trace" tests were also obtained on the seventh day, possibly due to some improvement in natural light conditions on the fourth, fifth and sixth days. Seven of the eleven "trace" tests secured occurred in samples taken from plants receiving urea alone, or in the combined spray, which suggests that urea had a greater, or at least a quicker, stimulatory effect on the soluble carbon level within the leaves than did sucrose. The pattern of values on day 8 in Replicate I bears out this trend, while values for Replicate II show no definite similar trend. Failure of soluble carbon to build up in Replicate II of the combined spray treatment is unaccountable.

The ability of urea to stimulate increases in leaf levels of soluble carbon presumably may be predicated either on mobilization of sugars from starch reserves within the plant, or on non-transfer of the soluble carbohydrates manufactured in photosynthesis to reserve starch. The former suggestion is in agreement with certain conclusions made by Kraus and Kraybill (27).

Under the low light conditions which were prevalent prior to initiation, and during the first seven days of

the experiment, it seems reasonable to expect that starch reserves and photosynthetic activity would both be at low levels, due to plant requirements for maintenance and new growth. The low or negative soluble carbon tests, as well as the failure of urea to stimulate large increases in leaf levels of soluble carbon following treatment appear to be explainable on such a basis.

An examination of the soluble nitrogen data in Table 6 shows that leaf levels of soluble nitrogen in the check plants averaged about 1320 p.p.m., which contrasts with the comparable average of 132 p.p.m. obtained in the field experiment. The greenhouse plant leaves, grown under winter light conditions, thus exhibit an extremely low soluble C/N ratio, due to large increases in soluble nitrogen and very significant decreases in soluble carbon. The soluble carbon and soluble nitrogen levels agree reasonably well with those of Emmert and Klinker (16), obtained under winter greenhouse conditions.

Inspection of the data for the urea treatment shows that urea stimulated very large, rapid increases in leaf levels of soluble nitrogen, with the maximum build-up occurring about the second or third day following spray application. Results from Replicate I indicate a more rapid rate and prolonged time of absorption than do those from Replicate II. Soluble nitrogen levels failed to rise appreciably in the com-

bined spray treatment. Whether this effect was due to the complementary action of sucrose absorbed and immediately utilized in amino acid and/or protein synthesis can only be speculated. If such was the case, then the sucrose-treated plant leaves should have shown some depression in soluble nitrogen relative to the combined treatment levels. A similar depression relative to check plant leaves might be expected only if protein synthesis was primarily involved and nitrogen was being converted to protein at a greater rate than it was being transferred to the leaves from the roots. Such a depression relative to both check and combined spray treatments can be observed with certainty only in the 1-day tests. The soluble carbon tests for both the sucrose and combined spray treatments are negative at the 1-day level. In general, the data suggest that any sucrose absorption probably occurred at a later date, possibly about the 3-day level, where lower levels of soluble nitrogen occurred coincidentally with "trace" tests for soluble carbon. The meager data on soluble carbon are insufficient to permit anything more than speculation with regard to sucrose absorption.

An analysis of variance was carried out on the soluble nitrogen data. Results of the analysis are presented in Table 8. There was a significant interaction between treatments and days of testing. "F" values were highly significant for both treatments and days. The L.S.D. of 486 calculated for treatments showed the urea treatment variance

Table 8. Results of analysis of variance carried out on the soluble nitrogen data of Table 6.

Source of Variation	D.F.	S.S.	M.S.	F	F for Sig. 5%	F for Sig. 1%
Total	-63	174,552.0	--	--		
Treatments	3	44,215.8	14,738.6	7.54**	3.07	4.87
Days	7	58,892.2	8,413.2	4.30**	2.49	3.65
Interaction	21	41,071.0	1,955.8	2.06*	1.91	2.51
Error	32	30,373.0	949.2			

Source of Variation	Mean	L.S.D.	$l_1 - l_2$	Significance
Treatments	1341	486 (1%)	855 - 1827	Urea only **
Days	1346	243 (5%)	1103 - 1590	Days 1,2,5 *

* Significant beyond 5% level; ** significant beyond 1% level.

to be highly significant. The sucrose and urea-sucrose treatments were insignificant. Due to failure to carry out analyses on day 0 prior to spray application, no valid day mean was available for the L.S.D. test in relation to days. Day 6 was arbitrarily selected as representing an equilibrium state following the effects of treatments, the L.S.D. for days was calculated and the data subjected to the test. Days 1, 2 and 5 only were significant at the 5% level. Inspection of the data shows that the urea treatment contributed to the significant variation on days 1 and 2, while generally increased levels of soluble nitrogen contributed to the significant variation

on day 5. It must be remembered that day effects due to the several treatments may be cancelled out in the mean values obtained for days, so little confidence can be placed on such a test in this type of experiment. The very high levels of soluble nitrogen on days 1 and 2 in the urea-treated plant leaves, however, can scarcely be attributed to factors other than absorption of nitrogen from the spray.

The rather large unaccountable variation between replicates on day 4 was subjected to the "t" test for paired data to assess the significance of this variation. The "t" value obtained was 2.39 ($t_{0.05} = 3.18$), which approaches the 10% level for 3 degrees of freedom. While the "t" value is insignificant, the difference between replicates seems too large to disregard. Environmental factors are not thought to be primarily involved, due to the fact that replicates within each treatment were located adjacent to each other and were therefore subjected to nearly identical conditions of light, temperature, etc. Treatments also received relatively uniform consideration with respect to the above-noted factors, so little variation which was directly related to these environmental influences would normally occur between treatments. Replicates, rather than treatments, were sampled and analyzed consecutively, so errors in the sampling or analytical procedure would not appear to be involved in the variation between replicates.

Urea spray failed to cause any leaf-burn during the first 7 days of the experiment. Following application of lights at 5:00 p.m. on January 2, some leaf-burn was evident on the urea-treated plants at 8:00 a.m. January 3. The burning observed at this time involved an estimated 5% - 20% of the area of individual leaves, all located within the upper third of the plants. A later examination at 2:00 p.m. of the same day showed that some increased burning had occurred. Also, the urea-sucrose treated plants showed some leaf-burn towards the tops of the plants. About 2/3 of the plant leaves on the upper third of the plants were affected to an estimated 5% - 10% of individual leaf areas. Observation of the plants every second day thereafter until January 16, when the lights were removed, indicated that most of the burning occurred during the first 24 hours after the lights were applied. Any further increase in the amount of burning was chiefly associated with affection of leaves closer to the base of the plants, rather than with progressive affection of previously burned leaves.

These observations suggest that leaf-burning is associated with higher light intensities and/or temperatures than obtained during the first 7 days of the experiment. A temperature check made on January 3 showed that there was a definite temperature gradient from top to bottom of the plants. The temperature at the growing tips averaged about 85° - 90° F., and was about 25° F. lower at the base of the plants, due to

a greatly decreased amount of heat radiation from the lamps at this distance.

A light intensity gradient naturally accompanies use of artificial lights, light intensity varying inversely with the square of the distances between the light source and the absorbing leaves. It seems reasonable to assume that either temperature or light, or a combination of both factors may have influenced the amount of leaf-burning which occurred in this experiment. Sucrose combined with urea did not completely inhibit leaf-burning, after artificial light was applied. Though soluble nitrogen in the urea and urea-sucrose treatments were at relatively normal levels by the 7th and 8th days, leaf-burning still occurred. This fact suggests that burning is not associated with relatively high levels of soluble nitrogen within the leaf due to urea absorption. The decreased ability of sucrose to inhibit burning on the 8th day may have been due to prior absorption and utilization within the leaf, as the data for soluble carbon suggest. Low light conditions would naturally favor rapid utilization of any sucrose absorbed.

Conclusions

1. Results of this experiment indicate that the nitrogen of urea sprays is rapidly absorbed by tomato plant leaves, the maximum build-up of soluble nitrogen within the plant occurring about 2 - 3 days following spray application.

2. Little direct evidence was obtained with respect to absorption of sucrose by tomato leaves, regardless of whether the sucrose was applied alone or in a combined spray with urea.

3. The soluble C/N ratio of tomato leaves, under conditions of the experiment, was very low in comparison with that found under summer field conditions, due to the combined effect of very high levels of soluble nitrogen and very low levels of soluble carbon.

4. Lack of reserve carbohydrate within urea or urea-sucrose treated plants, together with low rates of photosynthesis may have accounted for the failure of urea to stimulate large increases in leaf levels of soluble carbon observed in the summer field experiment.

5. The leaf-burning usually caused by urea foliage sprays may be a light and/or temperature dependent effect associated with higher levels of these factors than existed during the first 7 days of the experiment.

6. Burning of tomato leaves due to urea spray applications does not appear to be necessarily associated with low levels of soluble carbohydrates within the leaves.

7. No direct evidence of urea absorption from the urea-sucrose spray was obtained.

1952 SUMMER GREENHOUSE EXPERIMENT

Objectives

The experiment was initiated to determine whether tomato plants can utilize foliar spray urea as efficiently in growth and reproduction as root-fed urea or nitrate. It was also considered desirable to assess the modifying effects of sucrose on plant growth when applied in solution to the foliage along with urea.

Materials and Methods

Twenty-four young Early Alberta tomato plants previously grown in flats containing a 3:1 compost soil/sand mixture were lifted on May 30, the roots washed clean and transplanted, after recording individual weights, into 9-inch clay pots containing clean, sharp sand. The sand previously had been leached thoroughly to remove any appreciable amounts of nutrients.

The potted plants were placed in shallow watering pans on a central greenhouse bench, to facilitate sub-irrigation when it seemed desirable. Pots were arranged in a grid in six rows of four pots each, spaced one foot apart each way, permitting the imposition of four treatments with six replications.

During a two-week stabilization period following transplanting, all plants received a complete nutrient solution

as recommended by Ellis and Swaney (11). The plants soon became chlorotic, especially the basal leaves. A check on the sand medium nutrient levels by the Spurway quick soil-test method showed that nitrogen levels were inadequate while phosphorus levels were quite high.

Accordingly, a new nutrient formula was worked out having an N:P:K balance as recommended for tomatoes by Davis and Hill (9). By use of this formula plus supplemental feeding with NH_4NO_3, the plants were finally brought back to normal, and appeared relatively uniform and vigorous when treatments were commenced July 14.

The treatments applied were as follows:

1. NO_3(R) - plants received 50 cc. complete nutrient solution daily, containing 2.33 mg. nitrogen as nitrate.
2. Urea (R) - plants received 50 cc. complete nutrient solution daily, containing 2.33 mg. nitrogen as urea.
3. Urea (S) - plants received 50 cc. of N-free nutrient solution daily, plus (2.33 x 7 = 16.31) mg. nitrogen as urea; applied as completely as possible to the foliage in a 0.08 M. weekly spray.
4. (U + S)(S) - plants received 50 cc. of N-free nutrient solution daily, plus a weekly spray

combining urea, as in (3) above, with sucrose at the equi-molar rate of 0.08.

All pots were leached weekly with 2 - 3 quarts of water to remove any toxic accumulations of salts. Before applying spray nitrogen, pots were covered with a circle of masonite slotted to accommodate the plant stem. The open slot was covered with a strip of the same material, so that any spray drip occurring from the leaves was prevented from reaching the root medium. Spray was applied with a small hand sprayer capable of delivering all of the small volume of spray (7 cc.) necessary for each plant. While it was impossible to place all the intended spray solution on the plant, an estimated 80-85% remained on the plant, the chief loss being due to the fraction of the spray stream failing to contact the foliage. Loss by dripping from the leaves was very slight. By this method there was assurance that spray-treated plants could not receive in any way more than the amount of nitrogen fed by nutrient solution to the roots in the other treatments.

From July 29 to the completion of the experiment on September 3, the rate of feeding for all nutrients was doubled to compensate somewhat for the increased growth requirements of the plants.

Notes were taken during the experiment with regard to plant responses, and leaf samples from replicates 1 and 2 were checked for soluble carbohydrates and soluble nitrogen

levels on August 13. An early harvest of ripe fruit was taken and weights recorded on August 26, and the remaining fruits were harvested and weighed at the end of the experiment on September 3. Representative ripe fruits of the final harvest from two replicates of the experiment were analyzed for soluble carbohydrates and soluble nitrogen. Fresh weight records were taken of all the plant tops and roots, after which they were placed in paper bags, dried in a small laboratory oven at 50° C. for 4 days, and placed in dry storage, where they remained for 5 months. The material was then re-dried for 3 days at 80° C. in a forced draft oven, ground and re-dried for another day, after which the dry weight yields were recorded.

Results and Discussion

From the initiation of treatments on July 14 until the end of the experiment on September 3, plants of all the treatments grew fairly uniformly, though not vigorously. No obvious excesses or deficiencies appeared in the carbohydrate or nitrogen nutrition of plants in any of the four treatments. Blooming and fruit-set appeared quite normal, even though vegetative growth was limited.

The first signs of fruit ripening were observed in the Urea (R) treatment on August 2, followed by the NO_3 (R) treatment on August 8. First signs of ripening in the Urea (S) treatment were evident about August 10, and in the (U + S)

levels on August 31. [illegible]

taken and weights recorded on August 17, [illegible]

fruits were harvested and weighed [illegible]

on September 3. [illegible]

vest from the replicates of the [illegible]

delayed [illegible]

records were taken [illegible]

they were placed in [illegible]

oven at 70° C. [illegible]

they remained [illegible] days. [illegible]

for 2 days at 80° C. [illegible]

for another day, after which the dry [illegible] were recorded.

Results and Discussion

[illegible]

until the end of the experiment on September 3, [illegible]

the treatments [illegible]

[illegible]

in [illegible]

Blossom and fruit-set [illegible]

lative yields are [illegible].

[illegible]

in one time (a) treatment on August 7, [illegible]

treatments on August 8. [illegible]

treatment were [illegible] August 12, [illegible]

treatment about August 12. Figure 1 shows a representative plant from each treatment as of August 13, and indicates the definite gradation in ripening among fruits of the various treatments.

Figure 1. Representative plants from each treatment of the 1952 summer greenhouse sand culture experiment, showing the gradation in fruit ripening and general appearance of the plants on August 13, about 3 weeks prior to termination.

Analyses of soluble carbohydrates made on August 15 (see Table 9) showed slightly higher levels of soluble carbohydrates to be associated with the delay in onset of fruit ripening, particularly in the (U + S) treatment. Soluble nitro-

Table 9. Levels of soluble carbon (p.p.m. fresh-weight basis) present in leaves of tomato plants supplied nitrogen by 4 treatment methods, as of August 15, 1952. Numbers represent single determinations.

	TREATMENT			
Replicate	NO_3 (R)*	Urea (R)	Urea (S)**	(U + S)(S)
1	978	805	1115	1345
2	1345	1264	1047	1482
Average	1162	1035	1081	1414

* Nitrogen root-fed.

** Nitrogen fed in foliar spray

gen was negative (10 p.p.m. or less) in the leaves of all treatments, a reflection of the limited rate of nitrogen feeding.

Analyses of representative uniformly ripe fruits at the conclusion of the experiment (see Table 10) showed that the highest levels of soluble carbohydrates were associated with the use of sucrose in the (U + S) treatment, with the foliar method of urea nitrogen feeding, and to some extent with the previously noted delay in the onset of fruit ripening.

Fruit yields are given in Table 11, as summarized from the complete data in Appendix B - I, II, III, IV. The largest early yield of fruit was obtained from the Urea (R) treatment, while the largest total yield ripe and total fruit

Table 10. Levels of soluble carbon (p.p.m. fresh-weight basis) present in representative ripe fruits harvested from two replicates of 1952 summer greenhouse experiment.

	TREATMENT			
Replicate	NO_3 (R)	Urea (R)	Urea (S)	(U + S)(S)
1	5557	5729	6574	10,559
2	9284	5829	9777	10,058
Average	7421	5779	8176	10,309

Table 11. Mean yields of fruit (grams/replicate) harvested from 1952 summer greenhouse experiment.

	TREATMENT			
Harvest	NO_3 (R)	Urea (R)	Urea (S)	(U + S)(S)
Early Ripe, Aug. 26	121.4	174.4	146.5	149.7
Final Ripe, Sept. 3	150.3	80.4	129.6	114.2
Final Green, Sept. 3	41.9	62.3	42.1	36.0
Total	313.6	317.1	318.2	299.9

yields were obtained from the Urea (S) treatment. Total ripe and total fruit yields were quite similar for all treatments, however. Differences in early ripe and total fruit yield were

statistically insignificant (see Appendix B - VIII).

Table 12 summarizes data from Appendix B - V, VI, VII, for final fresh and dry weight of plant tops and roots, as well as giving the percentage dry matter contents. There was a depressing effect of the (U + S)(S) treatment on the growth of plant tops and roots, on either the fresh or dry weight basis. A very low moisture content of plant tops resulted in a high value of 20.8% for dry matter. Fresh and dry weights of plant roots showed only minor differences between treatments, being slightly the lowest in the (U + S)(S) treatment. Analysis of variance (see Appendix B - VIII) showed differences in final fresh and dry weights of the tops and roots to be statistically insignificant.

Table 12. Final mean fresh and dry weight of tomato plants (grams/replicate); plus percentage dry matter of plant tops and roots harvested from 1952 summer greenhouse experiment.

	TREATMENT							
	NO_3 (R)		Urea (R)		Urea (S)		(U + S)(S)	
	Top	Root	Top	Root	Top	Root	Top	Root
Final Fresh Weight	49.6	19.4	45.6	17.0	47.5	19.1	33.2	16.0
Final Dry Weight	8.28	2.26	7.15	1.84	8.06	1.98	6.94	1.72
% D. M.	16.7	11.7	15.6	10.8	17.0	10.36	20.8	10.8

The total increments in fresh weight per replicate during the experiment were 376.8, 373.5, 379.2 and 344.5 grams for the NO_3 (R), Urea (R), Urea (S) and (U + S)(S) treatments respectively (see Appendix B - VII for complete data). The depression in the (U + S)(S) treatment is in notable contrast with the equivalent values for all other treatments. Analysis of variance (see Appendix B - VIII) failed to show that this depression was a statistically significant treatment effect, possibly because of the small number of 6 plots involved in the trial.

Associated with the aforementioned depression, there were increased levels of soluble carbohydrates present in the leaves during the fruit ripening stages, and in the ripe fruits at the final harvest date. The levels of soluble nitrogen in all treatments were less than 10 and 5 p.p.m. in leaves and fruits, respectively, on the corresponding dates. Low leaf levels of soluble nitrogen were apparently a reflection of the low constant level of nitrogen nutrition employed; low levels in the fruits were perhaps partly due to rapid conversion to insoluble forms of nitrogen in the ripening fruits.

None of the plants in the experiment showed visible signs of obvious nitrogen deficiency during the treatment period, such as described by Kraus and Kraybill (27) and Nightingale (38). In the case of the (U + S)(S) treatment no symptoms (golden yellow color of foliage, epinasty, etc.) developed as have been noted by Went and Carter (59), where

sucrose foliar sprays were used for lengthy periods under good light conditions.

Just why sucrose in foliar spray exerted a depressing effect on growth is not clear. Similar depressions due to sucrose sprays were obtained by Went and Carter when tomatoes were grown with plenty of light at relatively low day and night temperatures (18° and 13° C., respectively). They offer no explanation as to why sucrose might have a depressing effect on growth. They did state that the effect was less apparent at higher temperatures, especially night temperatures, so increased respiration at the high temperatures probably aided in cutting down excessive internal concentrations of carbohydrates. Greenhouse temperatures generally in this experiment were as high or somewhat higher than those at which Went and Carter got growth depression, but still might have been low enough to be responsible for the effects observed.

Since a more or less sticky residue of sucrose builds up on the leaf surfaces with continued spray applications, it seems possible that stomatal and/or epidermal blockage or interference may ensue. Assuming such an effect to occur, abnormal gas relationships might be set up within the leaf, which would unquestionably have an adverse effect on respiration and possibly, also, on photosynthesis. No support for such an effect has been encountered in the literature reviewed.

Conclusions

1. Tomato plants, under the conditions of this experiment, utilized urea nitrogen sprayed on the foliage as efficiently as urea and nitrate nitrogen applied in nutrient solution to the roots.

2. There was a tendency for the onset of fruit ripening to be slightly delayed where urea spray nitrogen was fed. Further slight delay in the onset of fruit ripening was evident in the treatment receiving sucrose and urea in combined foliar spray.

3. Addition of sucrose to the urea foliar spray resulted in slight, consistent depressing effects on plant growth, as measured by (a) increment in fresh weight at termination of the experiment, (b) early ripe and final fruit yields, and (c) final fresh and dry weights of plant tops and roots. Statistical evaluation of the data indicated that these depressions might have no real significance.

4. Plants fed urea nitrogen in foliar spray, with or without sucrose addition, exhibited no obvious visible symptoms indicative of a major upset in their normal C/N relationships. Vegetation, blossoming, fruit setting and development proceeded in a normal manner, with the exception of certain effects already noted.

5. Slight leaf-burning, noted occasionally following application of urea spray, was prevented in the treatment which included sucrose and urea at equi-molar concentrations in the spray mixture.

1952 FIELD EXPERIMENT

Introduction

This experiment was initiated to obtain some idea of the trends in the internal levels of soluble carbohydrates and soluble nitrogen in tomato plant leaves, following application of urea and sucrose foliar sprays, separately and in combination. Secondarily, it was hoped that information as to the influence of sprays on the vegetative and reproductive performance of plants might be obtained by means of visual observations, records on height and spread of plants, rate of fruit ripening and on fruit yields.

Materials and Methods

The experiment utilized another portion of the land area previously described in the "materials and methods" section of the 1951 preliminary field trial. The area grew a crop of buckwheat in 1951, and was relatively fertile and in good tilth prior to use for this experiment.

Well-grown greenhouse transplants of Early Alberta tomato were set out in this area on June 7 at 4' x 4' spacing in four north-south rows of 18 plants each, plus a guard row of plants on either side and at each end of the area. The planting was staked out in a randomized block design, involving four treatments replicated six times, replicates numbering 1 - 6

in a north-south direction. Each treatment unit consisted of 3 plants. The central plant of each unit (replicates 1 and 2) was used to follow the fluctuations in soluble carbon and nitrogen after the first and second sprays on July 22 and August 4, respectively. No tests were made after the third spray application on August 15.

The spray treatments applied were as follows:

1. Check (no spray).
2. Urea (0.5 M. aqueous spray solution).
3. Sucrose (0.5 M. " " ").
4. (U + S) (urea plus sucrose at 0.5 equi-molar ratio).

Plants were covered thoroughly at each time of application, spray being discontinued before appreciable loss by dripping from the foliage occurred. Leaf levels of soluble carbon and soluble nitrogen were followed during a 12-day period after the first spray and during a 10-day period after the second spray. Tests were made daily for the first four days in each test period, and every other day during the remainder of each test interval.

The leaf samples were taken at 9:00 am. each test day during the first test period, and at 8:00 a.m. during the second test period. As in the 1951 field test, an attempt was made to select leaves of about the same physiological age and position on the plant, which were mature but not approaching senescence. It was attempted, also, to select leaves which had

not been shaded by other leaves for an hour or more prior to taking of the sample.

Washing, weighing, extraction and analysis of samples was completed immediately after selection of the samples. The methods of analysis were the same as used in the 1951 winter greenhouse experiment.

Records were taken on July 31 and September 8 on height and spread of plants. Total yields of green and ripe fruit were recorded at the time of harvest on October 1, a few hours before a severe freeze killed all the plants. Representative green and ripe fruits were selected from replicates 1 and 2 of each treatment at the time of harvesting. These were analyzed for soluble carbon and nitrogen one day later.

Some observations were recorded with respect to weather conditions prior to and during the two test periods, and some effects of the various treatments on the rate of fruit ripening were noted as the experiment progressed.

Results and Discussion

The mean levels of soluble carbon and nitrogen for each test period, plus the general averages for the whole experiment appear in Table 13, and are calculated from the complete data of Appendix C - I, II, III, IV. There was quite good

Table 13. Mean levels of soluble carbon and soluble nitrogen (p.p.m. fresh-weight basis) present in tomato leaves during two test periods following 0.5 M. aqueous spray treatment applications as indicated. (1952 field experiment)

	TREATMENT							
	Check		Urea		Sucrose		(U + S)	
Period	C	N	C	N	C	N	C	N
First (12 days)*	2081	277	1620	684	2227	405	2097	551
Second (10 days)**	1999	334	1770	726	1927	210	1829	614
Average	2040	306	1695	705	2077	308	1963	583

* Values are means of 16 determinations.
** " " " " 14 "

agreement between the mean soluble carbon levels in the various treatments for the first as compared with the second test period. There was a tendency for the level of soluble carbon to be depressed following the urea spray treatment in both test periods. No appreciable deviation from the average values in check plants can be associated with either the sucrose or (U + S) treatments. Thus, sucrose alone in foliar spray did not stimulate the leaf levels of soluble carbon. When combined with urea as in the (U + S) treatment, it largely prevented the depression in soluble carbon levels previously noted to be associated with urea alone in spray. Analysis of variance (see Appendix C - X (a)) of the complete carbon data failed to disclose a significant effect of treatments (F = 2.66; F at 5% level = 2.78). The approach

to the 5% level of significance suggests only that the lower soluble carbon levels present in the urea treatment may or may not be a real effect of treatment.

Soluble nitrogen levels were, in general, higher in the second than in the first period. The reason for reversal of the general trend in the sucrose treatment is not apparent. However, the soluble nitrogen level, as an average of both test periods, was the same in both check and sucrose treatments. Leaf levels of soluble nitrogen in the case of the (U + S) treatment were practically double the check levels for either test period. In the treatment of urea alone, soluble nitrogen levels were more than double check levels, as an average of each test period. These high average levels of soluble nitrogen were due chiefly to very large increases in soluble leaf nitrogen during the first 3 - 4 days following spray applications in both the urea and (U + S) treatments. (See complete data Appendix C - II, IV.) Analysis of variance of the complete soluble nitrogen data disclosed a highly significant effect of treatments ($F = 8.60^{**}$; F at 1% level = 5.09). Evaluation of treatment means by the L.S.D. test, using the check mean as the standard of comparison showed the urea and (U + S) treatment means to be significant to the 1% and 5% levels, respectively. (See Appendix C - X (b) for results of statistical analysis.)

In Figure 2 soluble carbon data for the three spray treatments are shown plotted as deviations from check

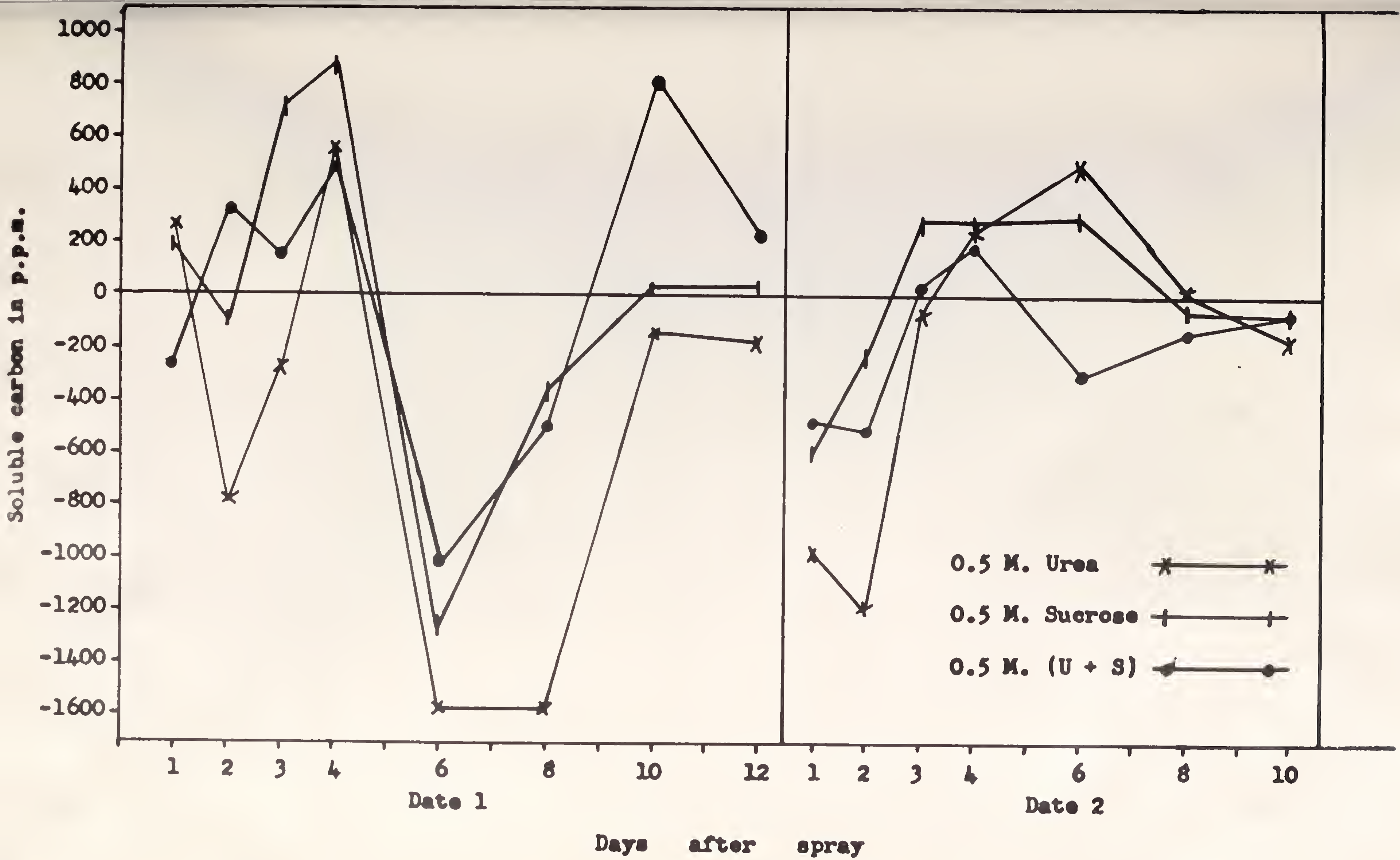

Figure 2. Levels of soluble carbon (p.p.m. fresh-weight basis) present in leaves of tomato plants during two test intervals following application of indicated spray treatments. (All points are plotted as deviations from average check levels of soluble carbon.)

values, for each test day following the two dates of spray application.

The strikingly large depressions in soluble carbon shown by all three spray treatments between the fourth and the tenth days after the first spray application seem unexplainable as treatment effects. The insignificant treatments F value of 2.66 (5% level = 2.78) does not assist in clarifying the nature of these depressions. (See Appendix C - X (a) for results of analysis of variance.) Such large deviations from check levels would seem, however, to be associated with some factor not influencing the levels of soluble carbon in check plant leaves.

The tendency, whether of significance or not, did not appear in the second test period, but a common tendency for depression of soluble leaf carbon at day 2 in both test periods can be seen to be associated with the urea treatment. This depression was pointed out in the discussion of data in Table 13. Apart from the above-noted tendency, the trends in soluble leaf carbon appear different for the two test periods. It is thought that the combined effect of the first and second spray treatments, plus the effects of less uniform weather conditions during the second test period contributed to the differences established. The differences in soluble carbon trends resulted in a statistically significant interaction effect between dates of spray application and days of sampling. (See Appendix C - X (a) for

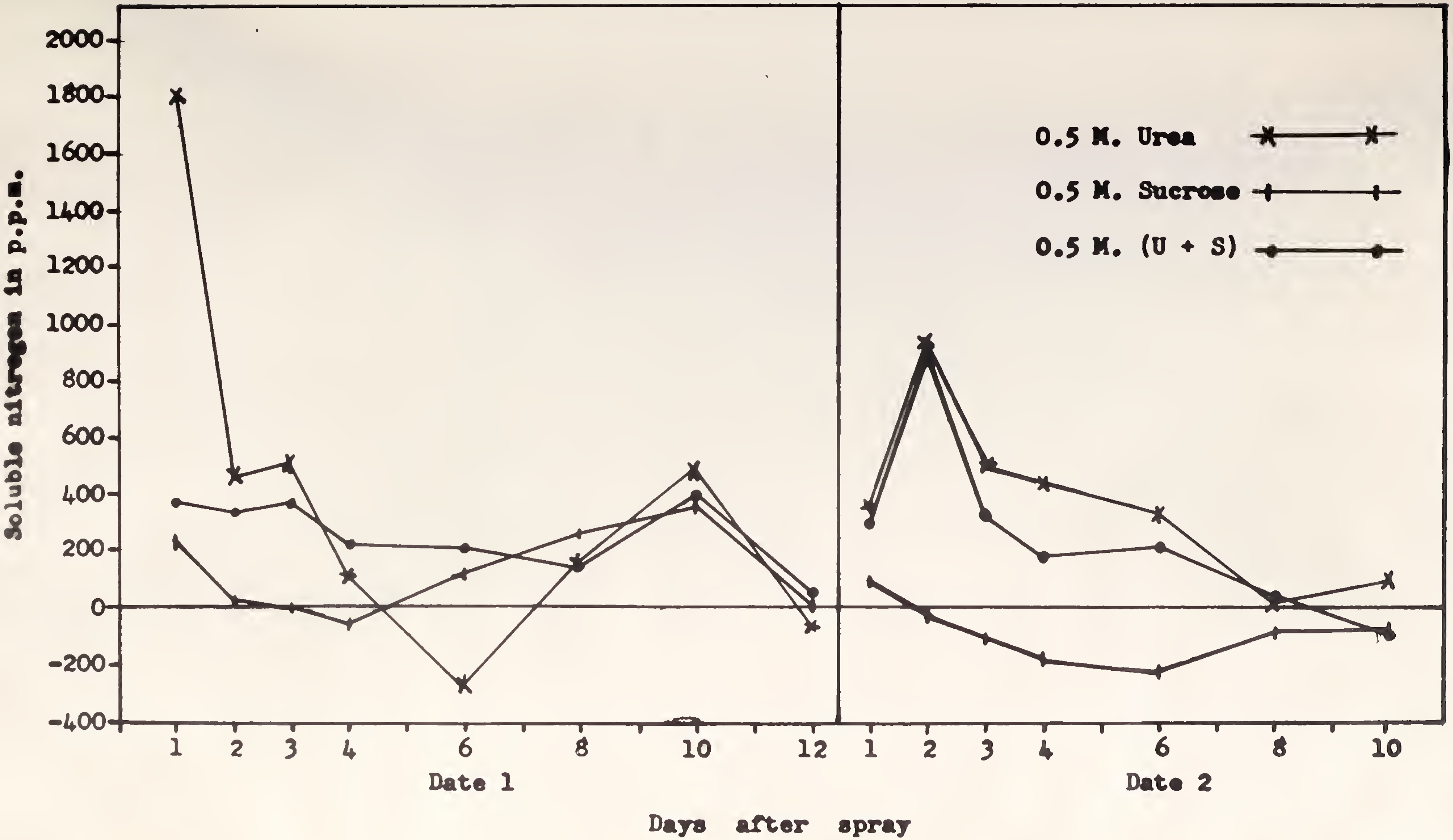

Figure 3. Levels of soluble nitrogen (p.p.m. fresh-weight basis) present in leaves of tomato plants during two test intervals following application of indicated spray treatments. (All points are plotted as deviations from average check levels of soluble nitrogen.)

results of analysis of variance; C - IX for weather observations.)

Figure 3 shows the soluble nitrogen data plotted in the same manner as for soluble carbon in Figure 2. The higher levels of nitrogen can be seen to be associated with the urea and (U + S) treatments throughout the greater part of either test period, with one exception - day 6 of the first test period in the urea treatment. There was a striking rise in soluble nitrogen on day 1 of the first test period in the urea treatment. When it is remembered that the data plotted on the graph are the means of replicate values, the high replicate value for this day of 3140 p.p.m. shows the abnormal levels to which soluble nitrogen can rise within the leaf. (See complete data in Appendix C - II.) Sucrose addition to foliar spray in the (U + S) treatment was effective in preventing such abnormal increases in internal soluble leaf nitrogen. A similar effect of sucrose is not apparent in the data for the second test period, coincident with increases in soluble leaf nitrogen in the urea treatment. The trend in all three spray treatments was toward the check levels of nitrogen as the end of each test period was reached.

Analysis of variance and application of the L.S.D. test to the complete soluble nitrogen data disclosed a highly significant effect of treatments, due to significant and highly significant increases in soluble nitrogen in the (U + S) and urea treatments, respectively. (See Appendix C - X (b).)

In Table 14 are given the four-day and overall soluble C/N ratios for each test period and for the experiment as a whole, calculated from the complete data of Appendix C - I, II, III, IV. Check C/N ratios were quite stable, regardless of the basis of calculation. On any of the three bases of calculation, there was a large depression in the C/N ratios of the two treatments receiving urea in spray, being largest where urea was applied alone. On the four-day basis, sucrose alone in spray resulted in slight consistent increases in the ratio during both periods; on the overall basis, there was some depression relative to check in the first test period and an increase relative to check in the second test period. On the basis of the complete data, the sucrose treatment ratio was equivalent to that of the check treatment.

Table 14. Soluble C/N Ratios* - 1952 field experiment.

	Four-day Averages			Overall Averages		
Treatment	Period 1	Period 2	(1+2)	Period 1	Period 2	(1+2)
Check	6.6	6.4	6.5	7.5	6.0	6.7
Urea	2.9	1.2	2.1	2.4	2.4	2.4
Sucrose	7.6	7.5	7.6	5.5	9.2	6.8
(U + S)	3.2	1.8	2.5	3.8	3.0	3.4

* Ratios, expressed as single values, represent average soluble carbon/average soluble nitrogen for the interval and treatment indicated.

In the first test period, the effect of sucrose in combined spray was to level out the rate of urea absorption by the leaves, coincidentally prolonging the period of absorption. The end result was that the interval levels of soluble carbon and nitrogen maintained a more normal relationship to each other and the C/N ratio did not drop to a value as low as was the case in the urea treatment.

In the second test period, soluble nitrogen rose to equally high levels relative to checks in both the urea and (U + S) treatments (see Figure 3). The 2-day peak, however, was still about 900 p.p.m. lower than the peak level for the urea treatment in the first test period. Whether sucrose failed to prevent increases in soluble nitrogen in the second test period seems debatable, but soluble nitrogen levels certainly did not reach the abnormally high concentration found at the one-day level in the first test period. The four-day C/N ratios of 1.2 and 1.8 for the urea and (U + S) treatments, respectively, (see Table 14) suggest that there was a more normal relationship between carbon and nitrogen in the (U + S) treatment during the early part of the second test period, regardless of the levels of soluble nitrogen. There is no direct evidence, however, that the more normal relationship present in the (U + S) treatment during this interval is to be definitely associated with absorption of sucrose.

The overall C/N ratios for the experiment indicate that the urea treatment resulted in a large depression in the

ratio, which was chiefly due to large increases in leaf levels of soluble nitrogen. The sucrose treatment had little effect on the ratio, while sucrose in the (U + S) treatment largely prevented the very large increases in interval leaf nitrogen associated with the use of urea alone in spray. The result was an approach, in the latter treatment, toward the more normal relationship between carbon and nitrogen over the whole experimental period.

There was a tendency toward an inverse relationship between the daily levels of soluble carbon and nitrogen. This tendency is clearly illustrated by the data for day 3 in the second test period (see Appendix C - III, IV). A cloudy, dull morning in this instance resulted in low and high levels of soluble carbon and nitrogen, respectively. Statistical evaluation of the effect of treatments on this tendency resulted in the following correlations between carbon and nitrogen, reproduced here from Appendix C - X (e):

Check	-	-0.477*
Urea	-	-0.272
Sucrose	-	-0.236
(U + S)	-	-0.492**

"r" for significance: 5% level = 0.374; 1% level = 0.478.

The significant correlation present in data for the check treatment supports the idea previously mentioned, that there is normally an inverse relationship between the daily levels of carbon and nitrogen. In the case of the urea and sucrose

treatments, the lack of significant correlation suggests that the normal tendency was upset, being restored when sucrose was added to the urea spray, as indicated by the highly significant "r" value of -0.492 for data of the (U + S) treatment.

In Table 15, data are summarized from Appendix C - VII, VIII to show the levels of soluble carbon and nitrogen found in green and ripe fruits at the end of the experiment. In the check and sucrose treatments, soluble carbon levels were higher in ripe than in green fruits. In the urea and (U + S) treatments, the change was toward lower levels with ripening. Lower levels of soluble carbon in ripe fruits generally were associated with all three spray treatments. These differences in soluble carbon content appear of doubtful significance in relation to treatments. Values for soluble nitrogen were lowest in the (U + S) treatment fruits. Differences, generally,

Table 15. Mean soluble carbon and soluble nitrogen levels (p.p.m. fresh-weight basis) found in mature green and ripe fruits harvested from 1952 field experiment.

		TREATMENT			
Class		Check	Urea	Sucrose	(U + S)
Green	C	5735*	7413	5670	6610
	N	56*	49	44	15
Ripe	C	8323	5979	7155	6022
	N	5⁻	5⁻	5⁻	5⁻

* All values represent the mean of 4 determinations.

were inconsistent and soluble nitrogen was too low to measure in the ripe fruits, being less than 5 p.p.m. in all instances.

The complete height and spread records of Appendix C - V, VI are summarized in Table 16. The records were taken on July 31, 9 days after the first spray application, and on September 8, about 3 weeks after the third spray application was made. Due to the determinate habit of Early Alberta tomato, most of the increase during this interval was in spread of plant. The data show that the urea treatment had slight adverse effects on the amount of vegetative growth made. This

Table 16. Mean increases in height and spread of tomato plants of the 1952 field experiment during the interval July 31 - September 8.

	Increase (inches)	
Treatment	Height	Spread
Check	2.1*	19.5
Urea	-1.2	14.5
Sucrose	0.0	19.1
(U + S)	-0.2	17.0

* All values represent the mean of measurements on 18 individual plants.

is to be expected because of the leaf-burn caused by urea at 0.5 M. spray concentration. Similar, but lesser, depressions

were associated with the (U + S) treatment. The sucrose treatment had no effect on spread increases, but did reduce the amount of growth in height.

Following each spray application there was a considerable amount of leaf-burn in the plants of the urea treatment, while little or no burn occurred in the (U + S) treatment. The burning commenced, or at least became visibly evident about the second or third day after spray was applied, about one day after the peak internal leaf level of soluble nitrogen was reached. Figure 4 gives some idea of the extent of leaf-

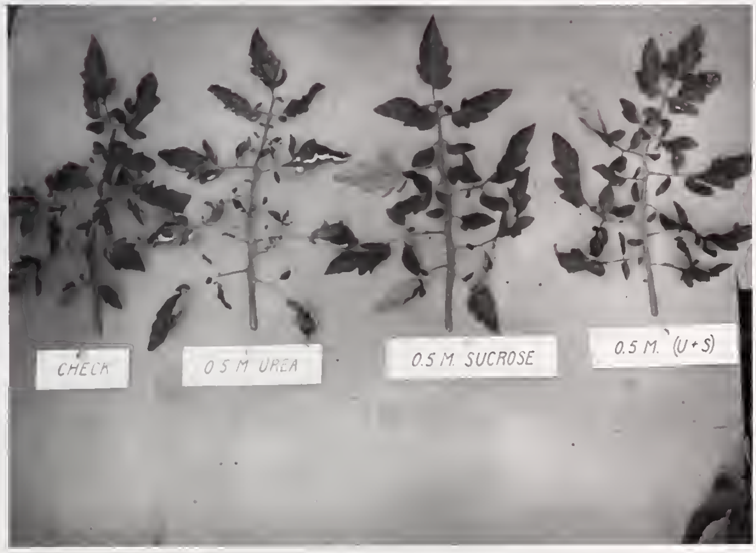

Figure 4. A photograph of representative leaves taken from plants in the 1952 summer field experiment, 5 days after the second spray application. The "burn" caused by urea alone in foliar spray is clearly evident. Note particularly the lack of similar "burn in the instance where sucrose was included in the combined spray.

burning due to use of the 0.5 M. urea spray, and shows the relatively normal appearance of leaves which received sucrose and urea plus sucrose in the spray mixture.

First ripening of fruit was observed in replicate 6 of the urea treatment on August 15. By September 4, all other replicates of the same treatment were also beginning to ripen fruit, and some ripening could be observed in most replicates of the remaining treatments. By September 8, the amounts of ripening fruit in the urea and sucrose treatments appeared equal due to rather belated but rapid ripening in the latter treatment. On the same date, the check and (U + S) treatments showed less ripening of fruits than was observed in the other treatments. By September 22, all observable differences in fruit ripening had disappeared. In general, then, the decreasing order of earliness in onset of ripening was: urea, sucrose, (U + S) and check. The earliness in ripening noted for the urea treatment is thought to be due to the "openning" effect of the urea spray, which permitted more sunlight to get at the fruits .

No adverse effects of treatments, other than previously noted, were observed with regard to flowering, vegetation or color of foliage, earliness of fruit set or subsequent development of the fruits.

The yields of green and ripe fruit are given in Table 17, which is a summary of the relevant data in Appendix C - VI.

Table 17. Mean yields (lbs. per replicate) of tomato fruits harvested from 1952 experiment.

	TREATMENTS			
Fruit Class	Check	Urea	Sucrose	(U + S)
Ripe	3.5	3.5	3.9	3.3
Green	28.1	22.3	24.5	24.4
Total	31.6	25.8	28.4	27.7

Inspection of the data indicates that there was little effect of treatments on either ripe, green or total fruit yields. In comparison with check yields, slight yield depressions were present in all the spray treatments, the lowest mean yield per replicate being obtained from plants of the urea treatment. Analysis of variance disclosed no significant effect of treatments on yield. There was a highly significant effect associated with replicates, due to a decreasing yield gradient from replicates 1 - 6. (See Appendix C - X (c), (d) for results of analysis.)

General Discussion

The results of this experiment indicate that 3 applications of the spray treatments used had only minor effects

on the vegetative, flowering or fruiting response of the plants. Favorable effects were not necessarily to be expected, since the performance observed in the check plants indicated that nitrogen from the soil was in good supply. The results of the chemical leaf analyses show that there were distinct effects of treatments on the normal course of metabolism, especially in the case of nitrogen.

The large increases in leaf levels of soluble nitrogen recorded 1 - 2 days after individual spray applications in the urea and (U + S) treatments confirm the conclusion drawn from results of the 1951 greenhouse experiment, with regard to the time of maximum urea absorption. Absorption of urea obviously occurred at a rapid rate as evidenced by the very high levels of soluble leaf nitrogen recorded at the 1 - 2 day intervals after spray application. As in the 1951 greenhouse experiment, no direct evidence of absorption of sucrose from foliar spray was obtained. Results of both experiments in this respect conflict with evidence presented by Emmert and Klinker (16). The modifying effect of sucrose is apparently not, as suggested by them, due to absorption and stimulus to internal levels of leaf carbohydrates. It appears rather to act by decreasing the initial high absorption rate for urea, while prolonging somewhat the period of active absorption. Results obtained are thus in line with those obtained by Cook and Boynton (8), as reported in 1952. If sucrose is absorbed from foliar spray, and there is considerable evidence to support this viewpoint

(14, 16, 47, 59), the rate of absorption must be relatively slow, or utilization and conversion to insoluble forms within the leaf quite rapid. The former postulation appears the more plausible, when it is remembered that single-celled plants immersed in water solutions of sucrose have been shown to take up sucrose very slowly (6). This knowledge is, in fact, made use of in producing cell plasmolysis in physiological studies of plant tissue (34).

That urea, alone or combined with sucrose, in foliar sprays can stimulate large, significant increases in leaf levels of soluble nitrogen is quite apparent from the results obtained. Once absorption has occurred, utilization should follow, in accordance with responses obtained with urea by a number of workers (14, 23, 26, 43).

The pathway of utilization appears to be as follows: The absorbed urea is hydrolyzed to NH_3 and CO_2 through the intervention of urease. Evidence for this reaction was obtained in a test to be discussed later in this paper, as well as by Kultscher as reported by McKee (32) and by Tukey et al (52) in tracer studies on woody plants. The NH_3 produced is then converted partly or wholly into amino acids and/or amide, depending on the most immediate requirement of the plant as well as the concentration of NH_3 involved.

Inspection of Figure 3 suggests that maximum internal leaf levels of urea occurred 1 - 2 days following spray application. The ensuing rapid drop in soluble nitrogen be-

tween days 1 - 2 and 2 - 3 in the first and second test periods, respectively, is believed to represent the stage where the absorbed urea was rapidly being hydrolyzed to NH_3. The drop in soluble nitrogen occurred because neither NH_3 or amide nitrogen are detected by the test used. The onset of leaf-burning, observed at this time, is then logically due to a building-up of toxic ammonia concentrations beyond the capacity of the plant to utilize in amino acid synthesis, or to detoxify through conversion to amide. Differences in soluble nitrogen levels between the urea and (U + S) treatments from the third to the sixth days in the first test period are postulated as being due to a predominance of amide over amino acid synthesis in the respective treatments. Changes occurring in these treatments from the sixth to the eighth day may represent transfer of the major portion of the amide and amino nitrogen to protein. These changes would agree, on the basis of nitrogen compounds detected by the test used, with present theories of nitrogen metabolism as advanced by Chibnall, Prianischnikow, Vickery et al, Gregory and Sen, Eckerson and others (7, 54, 55, 22, 10).

The high soluble nitrogen levels present in all three spray treatments as compared with checks at the 10-day level of the first test period are believed to be due to the inexplicably and unusually low soluble nitrogen levels found in check plant leaves. A treatment effect does not appear to be involved (see complete data Appendix C - II). Other variations in the chemical data cannot definitely be assigned as treatment effects.

Conclusions

1. Sucrose applied alone in foliar spray failed to stimulate internal leaf levels of soluble carbohydrates, as indicated by the chemical tests employed.

2. No direct evidence for absorption of sucrose from foliar spray was obtained.

3. When combined with urea in foliar spray, sucrose largely prevented the depressions in internal leaf levels of soluble carbohydrates that were found to be associated with the use of urea alone in the foliar spray.

4. Sucrose applied alone in foliar spray had no apparent effect on the internal leaf levels of soluble nitrogen.

5. Sucrose combined with urea in foliar spray probably acts in a manner such that the initial absorption rate for urea is reduced, while the period of absorption tends to be prolonged.

6. Urea, with or without sucrose, in foliar spray stimulated large increases in soluble leaf nitrogen. These increases were statistically significant as average increases over two ten-day examination periods following two consecutive spray applications spaced 14 days apart.

7. In general, increases in soluble leaf nitrogen associated with use of urea sprays on tomato foliage were greatest

from the first to the third day following spray application, and showed regression toward normal levels within 10 - 12 days.

8. A residual effect of the first application of spray treatments plus effects of the second application followed by variable weather conditions may have accounted for different trends shown in soluble carbon and nitrogen levels during two test periods.

9. Use of urea in foliar spray, with or without sucrose addition, resulted in large depressions in the leaf C/N ratios, as indicated by the chemical tests utilized. Depression was greatest where urea was applied without sucrose to the tomato foliage.

10. Sucrose applied alone in foliar spray caused slight, inconsistent fluctuations in the soluble C/N ratio of tomato leaves.

11. Sucrose addition to urea foliar sprays resulted in the maintenance of a more normal relationship between leaf levels of soluble carbon and nitrogen than was evident when urea was applied alone.

12. Urea alone in foliar spray had slight adverse effects on vegetation, as indicated by visual observation and records of height and spread of plants.

13. The leaf-burn usually occurring about 1 day later than peak internal levels of soluble leaf nitrogen, following application of urea foliar spray, is believed to be a result of toxic accumulations of ammonia derived within the leaf from the hydrolysis of absorbed urea.

14. There were no conclusive effects of spray treatments on the initiation or progress of fruit ripening.

15. The effect of spray treatments on fruit yields, both ripe and total, were slight and statistically without significance.

1952 FALL GREENHOUSE EXPERIMENT

Introduction

Due to the difficulty encountered with the complete nutrient solution used during the stabilization period in the summer greenhouse experiment, there was some doubt as to the validity of the results obtained. To determine more exactly plant responses to treatment, a second greenhouse sand-culture experiment was carried out during the fall and early winter.

Materials and Methods

The location and experimental design employed was the same as in the summer experiment. The treatments applied were similar to those of the summer experiment, with the exception that the daily rate of nitrogen feeding for all treatments was increased by about 50% to 3.5 mg. per day, while all other nutrient rates were essentially unchanged. The rate of feeding remained constant throughout the experimental period. The pots were again leached weekly with 2 - 3 quarts of water to remove any toxic salt accumulations.

Plants of Early Alberta tomato grown in a 3:1 compost soil/sand medium to an average weight of 8.9 grams were set in 9" clay pots containing sharp, thoroughly leached sand on September 17. They were fed a complete nutrient solution

for 30 days to permit them to become well established. Treatments were commenced on October 17, when the plants all appeared vigorous and of medium to dark green foliage color. One or two fruits were set on the first blossom cluster of nearly all plants. Treatments were ended with termination of the experiment on January 6, 1953, when plants were removed from the pots. Fresh-weight yields of ripe and green fruit and of plant tops and roots were recorded, after which the latter were placed in a forced draft oven and dried at 80° for 3 days. Following grinding in a Wiley-type mill, the top and root material was dried for a further day, after which dry-weight yields were obtained.

A count was made at the time of harvesting of the total number of fruits per replicate (replicate = per plant), as well as the number of fruits set which failed to begin sizing.

Analyses for soluble carbohydrates and soluble nitrogen were carried out on uniformly ripe representative fruits from each treatment. Refractometer readings for total soluble solids were obtained on juice expressed from several fruits, both ripe and green, from each of the four treatments, using a Bausch and Lomb 0-60% direct reading hand refractometer. Representative ripe fruits were also rated organoleptically for quality and flavor. Micro-chemical tests for starch were made on middle stem sections of plants of the four treatments, using the familiar $KI-I_2$ solution.

Results and Discussion

Following the commencement of treatments, all plants made reasonably good growth for about 1 month, with the exception that on October 30 the fruits set on all 6 replicates of the (U + S) treatment were noted as sizing very slowly when compared with those of the other treatments. Fruits of the NO_3 (R) treatment were sizing most rapidly at this date, followed closely by those of the Urea (R) and Urea (S) treatments, which were sizing at about equivalent rates. Figure 5 shows the general appearance of the experiment, and Figure 6 shows representative single plants of the four treatments at this time.

On November 28, two replicates of the Urea (R) treatment were showing signs of a greyish green chlorosis, chiefly about the margins and tips of leaves near the top of the plants. The chlorotic areas gradually increased and spread inward between the veins of the leaves. It was attended, or followed, by the appearance of purplish and/or yellowish blotches within the chlorotic areas. The symptoms as apparent did not seem clear-cut for any single element deficiency. When quick soil tests indicated potassium to be very low in the sand medium, supplementary potassium was tried and appeared to check progress of the chlorosis. Later, the same type of chlorosis in minor degree was noted on leaves of other plants in the Urea (R) and NO_3 (R) treatments, which only became obvious during the later stages of fruit sizing.

Figure 5. A photograph of the 1952 fall greenhouse experiment showing the general appearance of plants on October 30.

Fruit sizing, maturity and ripening continued at a very slow rate in the Urea with Sugar treatment, some plants failing to ripen any fruits by the time the experiment was concluded on January 6.

Table 18, containing data extracted from the complete data of Appendix D - II, indicates the relationships present with regard to the numbers and weight of ripe and green fruit harvested at the end of the experiment. The mean number and

Figure 6. A photograph showing the appearance of representative plants in each treatment of the 1952 fall greenhouse experiment on October 30.

yield of ripe fruit varied somewhat amongst the first three treatments, but there was a striking depression in these values in the case of the combination urea-sucrose treatment. This latter treatment, while setting a relatively large number of fruits, failed to size them normally, and ripened only one fruit amongst the 6 replicate plants. The low mean fruit yield of 68.2 grams, of which only 17.5% was ripened, together with the high mean number of 3.0 green fruits is in definite contrast with the smaller difference present in these values for the remaining treatments.

Table 18. Average numbers and yields (grams) per replicate; also percentage of fruit harvested as "ripe" from 1952 fall greenhouse experiment.

	TREATMENT			
Item	NO_3 (R)	Urea (R)	Urea (S)	(U + S)(S)
Ripe Yields	1.5* - 85.8	1.3 - 82.0	1.0 - 70.0	0.2 - 11.9
Green Yields	0.3 - 7.5	1.5 - 18.3	2.2 - 33.5	3.0 - 56.3
Total Yields	93.3	100.3	103.8	68.2
% Ripe Fruit	92.0	81.5	67.7	17.5

* Average number of fruits for yield indicated.

The data of Table 19, withdrawn from the complete data of Appendix D - I show in summarized form the yield records for plant tops, roots and fruits at the end of the experiment, as well as the starting weight of plants and increment in fresh weight during the experiment. Urea alone, whether root or spray

Table 19. Mean fresh-weight yields (grams/replicate) of plant parts at final harvest, plus mean starting weights and mean increment in fresh weight during the experimental period.

	PLANT PART or ITEM				
Treatment	Starting	Top	Root	Fruit	Increment
NO_3 (R)	10.0	25.6	8.6	93.3	117.6
Urea (R)	9.0	32.9	10.1	100.3	134.2
Urea (S)	9.1	27.7	10.7	103.8	133.2
(U + S)(S)	7.6	35.1	13.1**	68.2	108.8

** Increase highly significant statistically.

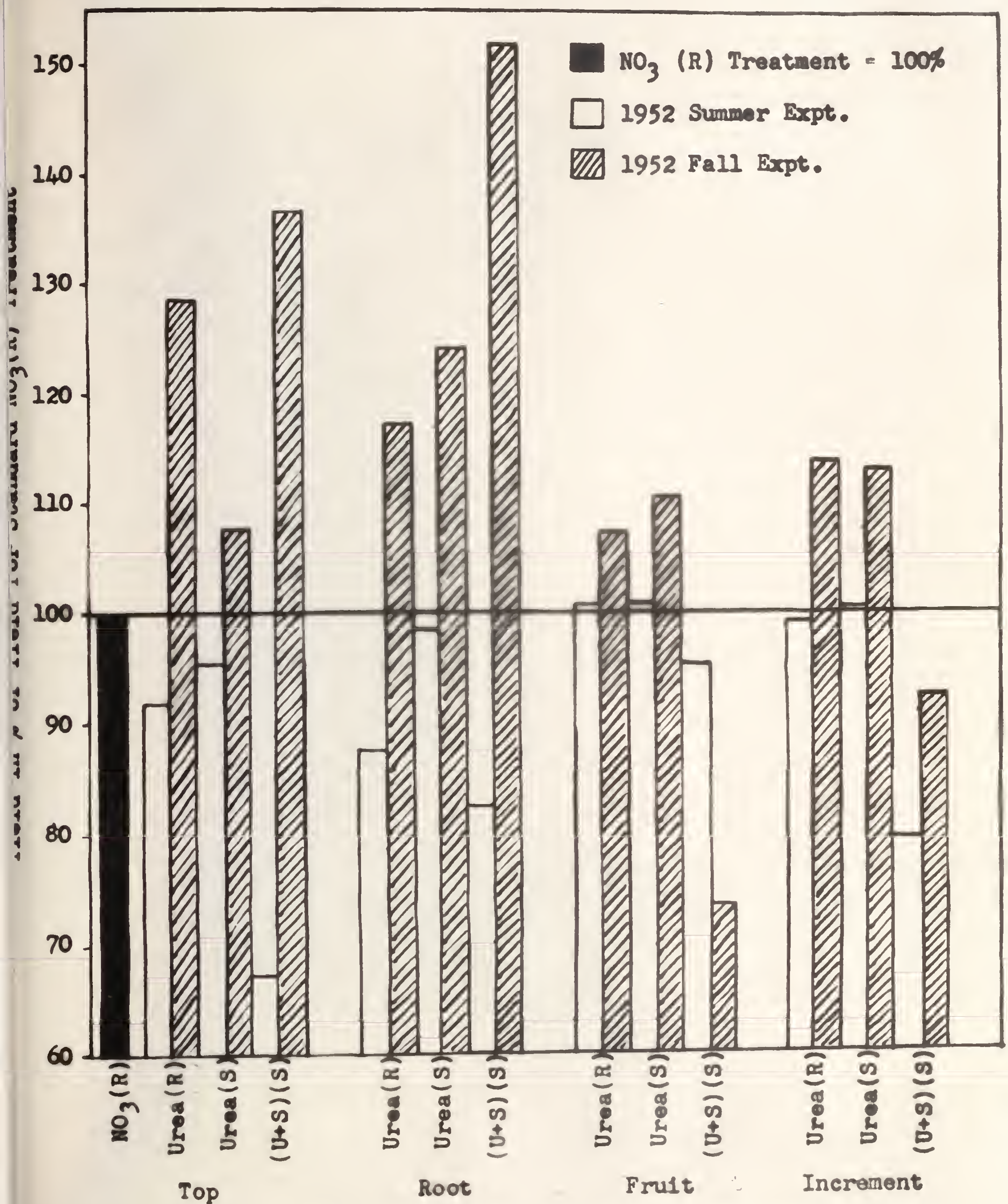

Figure 7. Histographic comparison of fresh weight yields of plant parts, plus increment in fresh weight during the experimental periods for the 1952 summer and fall greenhouse experiments. Values for the nitrate-fed plants are taken as 100% in all instances.

fed, resulted in an almost equivalent growth response, so far as the fresh weight distribution in tops, roots and fruits was concerned. Nitrate-fed plants showed proportionate depressions in all these values compared to the two treatments previously mentioned, despite a higher average starting weight. The (U + S) treatment, with the lowest starting weights, produced the highest fresh-weight yields of tops and roots, but these were more than offset by depressions in fruit yield, so that the total fresh-weight increment was slightly depressed. Fruit yields of the other treatments were practically equal. Statistical evaluation of the above variations showed there was a highly significant increase in the fresh-weight root yields in the (U + S) treatment. (See Appendix D - IV for results of statistical analysis.)

The histogram of Figure 7 indicates graphically differences in the distribution of growth in the fall as compared with the summer greenhouse experiment. The difference in plant response to sucrose additions to the foliar spray under summer and early winter conditions is very evident. Much more of the total growth made was present in the tops and roots under winter conditions, while growth expressed in fruit yield was depressed under winter as compared with summer conditions.

The mean dry-weight yields of plant tops and roots appear in Table 20, plus percentage dry matter, as calculated from the complete data of Appendix D - I, III. Variations

Table 20. Mean dry weights (grams/replicate) of plant tops and roots, plus mean percentage dry matter content, at final harvest date of 1952 fall greenhouse experiment.

	TREATMENT			
Item	NO_3 (R)	Urea (R)	Urea (S)	(U + S)(S)
Top Yield	3.036	4.075	3.923	5.222**
% D.M.	11.85	12.39	14.16	14.88
Root Yield	1.047	1.149	1.263	1.524
% D.M.	12.17	11.38	11.80	11.63

** Increase highly significant statistically.

between treatments were small, except for a large increase in the dry-weight yield of tops in the (U + S) treatment. Analysis of variance and application of the L.S.D. test to the complete data showed this increase to be highly significant when compared to the dry-weight yield for the standard NO_3 (R) treatment. (See Appendix D - IV (e) for results of analysis.) The percentage dry matter was relatively uniform in all treatments, with the exception of some increase for plant tops where spray nitrogen was fed, and more particularly where sucrose was included in the combined foliar spray.

Table 21 shows the effect of treatments on fruit setting, sizing and mean weight per fruit classes as "sized." All fruits which had begun sizing - i.e., were at least ½" in diameter when harvested - are included in the latter category.

Table 21. Data from 1952 fall greenhouse experiment showing numbers of fruit set, sized, percentage sized as well as the mean weights per sized fruit in the four treatments employed.

	TREATMENT			
Item	NO_3 (R)	Urea (R)	Urea (S)	(U + S)(S)
No. of fruits set	50	71	69	59
No. of fruits sized	11	17	19	19
% of set fruits sized	22	24	27.5	32
Mean Wt./sized fruit	8.5	5.9	5.5	3.6

Other data of the table are as calculated from complete data of Appendix D - II. Urea, whether root or spray-fed, produced a slightly greater set of fruit than root-fed nitrate. Urea on the same basis, had a depressing effect on the final size attained by individual fruits. Addition of sucrose to urea spray resulted in a further depression in the final size of fruits.

Results of the analysis made on ripe fruits appear in Table 22. Soluble nitrogen was less than 10 p.p.m. in all cases and no data are presented. The relative levels of soluble carbohydrates between treatments were much the same as in the summer experiment, with the exception that in this experiment the fruits of the NO_3 (R) treatment were lowest in soluble carbohydrates rather than the Urea (R) treatment. The general level for all treatments was 1,000 - 2,000 p.p.m. lower than in the summer experiment, probably due to the poor light conditions.

Table 22. Concentrations of soluble carbon (p.p.m. fresh-weight basis) present in ripe fruits at final harvest date of 1952 fall greenhouse experiment.

	TREATMENT			
Duplicate	NO_3 (R)	Urea (R)	Urea (S)	(U + S)(S)
1	5110	6230	6515	8093
2	4768	6315	6345	7720
Average	4939	6273	6430	7907

Data on the percentage total soluble solids present in green and ripe fruits appear in Table 23. Single values represent the average of single determinations on 2 green fruits; and of from 5 - 7 single determinations on individual ripe fruits, except for the (U + S) treatment where only one ripe fruit was available. The value in the latter instance is the mean of duplicate determinations on the single fruit.

Table 23. Percent total soluble solids present in expressed juice of green and ripe fruits harvested from 1952 fall greenhouse experiment.

	TREATMENT			
Class Fruit	NO_3 (R)	Urea (R)	Urea (S)	(U + S)(S)
Ripe	4.21	4.36	5.00	6.25
Green	3.75	5.25	4.50	5.25

These data show generally the same trend as was obtained by use of the soluble carbon test, with the exception of the value for the Urea (R) treatment in the "green" class.

Ripe fruits of the NO_3 (R) and Urea (R) treatments were rated as of good quality and flavor in an organoleptic test. Fruits from the Urea (S) treatment were considered fairly good in quality and flavor, but less appealing than those of the previously mentioned treatments. The single ripe fruit from the (U + S) treatment was classed as obviously sweeter than any of the others, texture was good, and acidity was either very low or masked by the high sugar content.

The following observations were made as a result of the microchemical tests for starch on middle stem sections of plants:

(1) NO_3 (R) - Some starch was present in most of the pith parenchyma cells. However, there were no increased accumulations of starch in cells adjacent to the vascular tissues, as appear in typical nitrogen-starved plants. The proportion of pith to vascular tissue appeared rather high.

(2) Urea (R) - There was practically no evidence of starch in any of the tissues. The proportion of pith to vascular tissue appeared about normal.

(3) Urea (S) - There was practically no evidence of starch in any of the tissues. Cells of the central part of the pith were more or less broken down. The proportion of pith to vascular tissue appeared about normal.

(4) (U + S)(S) - A very large accumulation of starch was present in all cells of the pith, with especially large accumulations in parenchyma cells adjacent to the vascular bundles. The starch content of these stems was estimated to be about five times that present in stems of the nitrate-fed plants.

As was true of the summer greenhouse experiment, there were no major effects of treatments on increase in fresh weight, fresh weight of plant tops or dry weight of roots. Under low winter light and to some extent low temperatures in the greenhouse, there was an increased inhibition of fruit development and ripening in the (U + S) treatment, as compared with results obtained in the summer experiment. Associated with this inhibition, there were depressions in total fruit yield, large accumulations of starch in the stems, and increases in dry-matter content of both roots and tops. In the last instance, the increase was highly significant statistically, as was previously noted. The fresh-weight yield of root material was quite high in comparison to that for the NO_3 (R)

treatment, the difference being highly significant statistically. Thus, just when sucrose in foliar spray might be expected to have a favorable effect on growth, under low winter light conditions as has been suggested by Went and Carter (59) and Emmert and Klinker (16), the opposite effect was obtained, especially with respect to fruit development.

Associated with the effects already discussed, green and ripe fruits of the (U + S) treatment apparently contained the highest concentrations of soluble carbohydrates present in any of the treatments, and while a normal or above-normal number of fruits were set, there was a relative failure of development beyond the initial stages of fruit sizing. Failure to develop beyond this point was accompanied by failure of fruits to ripen.

Fruit ripening was also delayed somewhat in the urea foliar treatment, but fruit development otherwise proceeded in more or less normal fashion, with no accumulation of starch appearing in the stems, at least visibly during the experiment, or as indicated by the microchemical tests at the end of the experiment.

If, in the (U + S) treatment, it be postulated that continued sucrose spraying prevented the spray urea from being absorbed, then lack of nitrogen for protein synthesis might explain the inhibiting effect of sucrose on fruit development. Plants of this treatment showed no visible symptoms to

suggest they were more limited in their nitrogen nutrition than plants of the Urea (S) treatment (e.g., yellowing of basal leaves, etc.). With the limited nitrogen regimen employed, much inhibition of urea absorption by sucrose in the spray would almost certainly have resulted in visible nitrogen deficiency symptoms, so such an explanation does not appear plausible. Moreover, the vegetative development of the sprayed plants suggested at least an equal amount of available nitrogen when compared to root-fed plants.

The results suggest that in the (U + S) treatment fruit development may have been inhibited by a lack of nitrogen in the young fruits, necessary for cell division and/or enlargement to some extent. Just why or how movement of nitrogen to the meristematic regions of the young fruits could be blocked has not been established. Conceivably continued weekly applications of sucrose in foliar spray, which do result in the building-up of a more or less sticky residue on the leaf surface, may have blocked or interfered mechanically with normal stomatal processes including either or both of CO_2 and O_2 diffusion. Under low winter light conditions, which are unfavorable to high photosynthetic activity, such a blockage would tend to favor high and low internal concentrations of CO_2 and O_2, respectively, as a result of high respiration rates relative to those for photosynthesis. The high levels of CO_2 would have a depressing effect on plant respiration, the end result being a depression of anabolic processes for lack of energy normally

provided through respiration of carbohydrates. The latter would then tend to accumulate, as further sucrose absorption occurred. A much more refined experiment would, of course, be required to test the validity of such a hypothesis. It seems, however, to explain reasonably well the lesser depressing effects of sucrose noted under summer conditions. In this instance, blockage effects would be minimized due to the increased ascendancy of the photosynthetic process. The latter, by utilizing immediately CO_2 released internally in respiration, would neutralize blockage effects to a certain extent.

Conclusions

1. Urea nitrogen, whether root or spray-fed, resulted in an equivalent vegetative and reproductive response in tomato plants to that obtained with root-fed nitrate; with the exception that, in the case of urea-spray feeding, the onset of fruit ripening was definitely delayed. Mean weight per sized fruit was also somewhat depressed as a result of both methods of urea feeding, in comparison to the value for fruits receiving the standard root-fed nitrate.

2. Sucrose combined with urea in foliar spray resulted in what is speculated as an upset in normal metabolism. The relevant effects noted were: (a) highly significant increases in root fresh weight and top dry matter;

(b) large accumulations of starch in the middle stems;
(c) extended delay in the onset of fruit ripening, and
(d) depressions in rate of fruit sizing and final fruit yield.

3. Delays in fruit development associated with the (U + S) treatment are postulated as being due to sucrose-induced internal metabolic upsets which blocked movement into the fruit of nitrogen for protein synthesis.

4. Under conditions of a constant and relatively low rate of nitrogen feeding, no typical visible symptoms of either carbohydrate excess or nitrogen deficiency were observed in any of the treatments.

1953 LIGHT, TEMPERATURE, AND HUMIDITY TESTS

High Temperature Tests

Two tests were conducted in an inexpensive indoor growth chamber with young Early Alberta tomato plants 8" - 10" in height, sprayed before treatment with 0.5 M. urea solution. Both tests used three light intensities supplied by fluorescent units. The intensities were approximately 125,350 and 650 foot-candles, as shown by measurements made with a General Electric Type DP-9 foot-candle meter. For both tests, the temperature was held to $24 \pm 3^{\circ}$ C.

The first set of plants was exposed to the above conditions at a relative humidity of $88 \pm 2\%$. The second set received similar treatment except that the relative humidities for day and night were $45 \pm 7\%$ and $60 \pm 10\%$, respectively. Both sets of plants received an eight-hour photoperiod plus slight additional natural light.

Results

1. High Constant Relative Humidity and Temperature.
   All water of the spray solution apparently disappeared from the leaf surfaces about 3 hours after treatment was started, leaving no apparent spray residue. Injury was evident on the leaves of all plants at all three light intensities 24 hours after treatment had been commenced,

and the plants had received only one eight-hour photoperiod. After a further 24 hours, treatment was discontinued and the humidity was allowed to drop, with the result that the relative amounts of leaf injury soon became evident as the "burned" tissue dried up. Injury increased progressively with decrease in the light intensity applied. At the low light level, a minimum of 70 - 90% of the total leaf area of individual plants was affected. The percentage injury was less at the intermediate light intensity and was estimated to be 40 - 50% of total leaf area at the high light intensity. Further observation of the plants over a three-day period at low relative humidity confirmed the above-noted trend. The only plants apparently surviving then were those treated at the highest light intensity.

2. <u>Variable Relative Humidity and High Temperature</u>.

Close observation of plants following application of treatment showed that water of the spray solution had disappeared from the leaf surfaces within 2 - 3 hours, leaving a crystalline residue of urea on the leaf surfaces. After 24 hours of treatment, there were some signs of leaf injury, most evident on leaves of plants at the intermediate light intensity. After a second photoperiod (32 hours of treatment), definite leaf injury could be observed at all light levels, the order of severity being similar to that observed at constant high rela-

tive humidity. However, the extent of injury was much less in all instances, such that plants at the highest light intensity were little injured. After 48 hours of treatment, the order of severity and extent of injury were substantially unchanged. The estimated percentages of injured leaf tissue were as follows: low light, 15 - 25%; intermediate light, 12 - 20%; high light, 5 - 8%.

Subjection of these plants to a further 24 hours' treatment at 90% relative humidity, followed by an 8-hour period at 20 - 30% relative humidity, resulted in some further progress of leaf injury which appeared about the same at all light levels.

Re-spraying of single leaves of plants at all light levels plus re-imposition of a 24-hour period at 90% relative humidity was effective in severely injuring only those leaves which had been re-sprayed. This was particularly apparent at the two lower light levels.

Low Temperature Tests

Two sets of Early Alberta tomato plants 8" - 10" high were sprayed with 0.5 M. urea solution and placed in a controlled temperature chamber at $10 \pm 2^{\circ}$ C. One set of plants received low light, the other set high light, the intensities in this instance not being measured; they were estimated to be approximately 100 - 200 fc. and 350 - 400 fc., respectively. All plants received an eight-hour photoperiod plus any addi-

tional natural light available in the greenhouse morning and evening. Close control of the relative humidity was attempted but found impossible. It ranged from 40 - 65% during the photoperiod and rose to 80 - 90% during the nights.

Twenty-four hours after treatment (1 photoperiod), no injury could be observed at either light level. After a second eight-hour photoperiod, the first signs of injury could be seen on the leaf-tips, more particularly on the plants at the low light intensity. Following a further 16 hours of treatment, injury was quite definite, with greatest injury being evident at the low light level. The greatest amount of injury, however, was estimated at only 5 - 10% of the total leaf area of individual plants. After a three-day period under ordinary greenhouse conditions of about 18° C. and 55% relative humidity, the injured areas of leaves became sharply delineated, but there was no progressive injury.

Conclusions

1. Within the limits of the experimental conditions used, low temperature, high light intensity and low relative humidity following application of urea foliar spray were instrumental in reducing the severity of leaf injury normally associated with use of the higher spray concentrations above 0.1 molar.

2. These tests suggest that light intensity, temperature and relative humidity often may combine in such a way as markedly to prevent, reduce or increase the amount of injury sustained by tomato leaves following spray applications of urea. Of the three factors mentioned, high and low levels of light and temperature, respectively, are believed to be of greatest importance in reducing, or preventing, urea foliar spray injury.

TESTS FOR UREASE ACTIVITY

These tests were made to determine whether urease is present in tomato plant leaves, and to note effects of low and high temperature, as further indication of enzyme activity.

Two sets of treatments were prepared in 125 cc. Erlenmeyer flasks as follows:

(1) 20 - 30 cc. of 0.24 M. urea solution (control).

(2) 20 - 30 cc. distilled water plus 3 - 4 tomato leaflets.

(3) 20 - 30 cc. 0.24 M. urea solution plus 3 - 4 tomato leaflets.

The flasks were stoppered and one set incubated at 8° - 10° C., the other at 37° - 39° C.

A tabular summary of the results obtained appears below.

Table 24. Results of incubation tests with tomato leaves, as an indication of the presence and activity of urease.

Treat. No.	Incubation Time (hrs.)	8° - 10° C.	37° - 39° C.
1	2 - 3	Negative for NH_3	Negative for NH_3
	8 -10	" " "	" " "
2	2 - 3	Negative for NH_3	Negative for NH_3
	8 -10	" " "	" " "
3	2 - 3	Slight NH_3 evolution	Active NH_3 evolution
	8 -10	" " "	Continued active NH_3 evolution

There was wilting of leaves in treatment 3 at both temperatures. It was not evident at the low temperature until leaves had been incubated for over a day. At high temperature, wilting was noted in 8 - 10 hours, coincident with the large accumulation of NH_3 in the Erlenmeyer flask.

Conclusions

The results obtained indicate that urease is present in tomato leaves. A decreased rate of activity was observed at the low, as compared with the high, temperatures tested, an effect associated with most chemical reactions of an enzymatic nature.

GENERAL CONCLUSIONS

1. Tomato plants, under the experimental conditions imposed in two sand culture tests, were apparently able to utilize urea nitrogen fed in a foliar spray as efficiently as urea or nitrate nitrogen fed in nutrient solution to the roots, with the exception that there was slight delay in the onset of fruit ripening.

2. Under summer greenhouse conditions, the addition of sucrose to the urea spray mixture resulted in consistent but slight depression of plant growth as measured by: (a) increment in fresh weight; (b) first ripe and final fruit yields; and (c) final fresh and dry-weight yields of plant tops and roots.

3. Under winter greenhouse conditions, sucrose additions to urea foliar spray resulted in what is speculated as an upset in normal plant metabolism. The relevant effects noted were: (a) highly significant increases in the fresh weight of roots and dry weight of tops; (b) large accumulations of starch in the middle stems; (c) extended delay in the onset of fruit ripening; and (d) depressions in the rate of fruit sizing and final fruit yield.

4. Under greenhouse sand culture conditions, tomato plants fed with urea nitrogen in foliar spray, with or without sucrose additions, exhibited no obvious visible symptoms

indicative of a major upset in their normal C/N relationships. Vegetation, blossoming, fruit-set and development proceeded in a normal manner, with the exception of certain effects already noted.

5. No direct evidence was established for absorption of sucrose applied in foliar sprays. The possibility of prolonged but very slow absorption along with rapid utilization or conversion to starch is not excluded.

6. Urea applied to tomato leaves in foliar spray stimulated very rapid statistically significant increases in soluble leaf nitrogen one to two days after sprays were applied, with regression toward normal levels occurring within 8 - 12 days after individual spray applications.

7. Sucrose combined with urea in foliar spray probably acts in a manner such that the initial absorption rate for urea is reduced, while the period of absorption tends to be prolonged.

8. Urea as a foliar spray, with or without sucrose addition, resulted in large depressions in the leaf C/N ratios, as indicated by the chemical tests performed. Depression was greatest where urea was applied alone to the leaves.

9. The leaf-burn usually occurring about one day later than peak internal levels of soluble nitrogen following

application of urea foliar spray is believed to be a result of toxic accumulations of ammonia, derived within the leaf from the rapid enzymatic hydrolysis of absorbed urea.

10. Sucrose added to urea foliar spray solutions was found effective in lessening or preventing the leaf-burn normally associated with the application of urea sprays to tomato leaves.

11. Under field conditions, there were no conclusive effects of urea, sucrose or urea-sucrose foliar sprays on the initiation and progress of fruit ripening or fruit yields.

12. Limited tests involving light, temperature and relative humidity indicated that high light intensities together with low temperatures may be of greatest importance in reducing or preventing urea foliar spray injury. High temperature combined with high relative humidity appears to favor a relatively steady high rate of urea absorption by tomato leaves.

13. Results of the 1951 field trial indicated that urea foliar sprays might have a stimulatory effect on soluble leaf carbohydrates; this conclusion is herewith withdrawn since there was no definite evidence from subsequent experimental results to support it. The

increased levels of soluble leaf carbon obtained in the 1951 field trial where urea and urea-sucrose foliar sprays were applied may well have been artifacts resulting from failure to wash leaf samples prior to carrying out analysis.

ACKNOWLEDGMENTS

This research project was carried out under the supervision of Dr. R. J. Hilton in the Research Laboratory of the Department of Plant Science, University of Alberta, and while the author held a Bursary and Studentship under the National Research Council of Canada. Gratitude is expressed to the National Research Council, and to the Department of Veterans Affairs, whose invaluable financial assistance has made this work possible.

Sincere and grateful acknowledgment is made to: Dr. R. J. Hilton, for helpful advice and constructive criticism during the investigation and during preparation of the manuscript; Dr. J. H. Whyte, of the Department of Botany, for advice and assistance in carrying out physiological tests; Dr. A. W. Henry, of the Division of Plant Pathology, for making available necessary facilities; Dr. S. Zalik and Mr. W. D. Evans, for constructive advice on statistical aspects; Miss J. Stewart, for typing the manuscript; Mr. M. Ostifichuk, for photographic work; and Mr. G. Jutte, for assistance in certain aspects of the field work.

ACKNOWLEDGMENTS

This research project was initiated and under the supervision of Dr. [illegible] Wilson in the [illegible] laboratory of the Department of Plant Science, University of Alberta, and while the author held a Bursary and [illegible] from the National Research Council of Canada. [illegible] of the original research [illegible], and [illegible] Alberta, these [illegible] financial [illegible] have made this work possible.

Sincere and grateful acknowledgment is made to: Dr. [illegible] Wilson, for helpful advice and constructive criticism during the investigation and during preparation of the manuscript; Dr. [illegible], of the Department of [illegible], for advice and assistance in [illegible] and [illegible]; Dr. [illegible], of the Division of Plant [illegible], for [illegible]; Dr. [illegible] and Dr. [illegible], for [illegible]; Miss [illegible], for typing the manuscript; Mr. [illegible], for photographic work; and Mr. [illegible], for assistance in certain aspects of the field work.

Bibliography

1. Anonymous. Now leaves eat too. Flower Grower 37: 28. April, 1950.

2. ________. Wallace's Farmer, p. 62. February 18, 1950.

3. Beckenbach, J. R., W. R. Robbins and J. W. Shive. Nutrition studies with corn III. A statistical interpretation of the relationship between nutrient ion concentration and the carbohydrate and nitrogenous content of the tissue. Soil Sci. 49: 219-238. 1940.

4. Blackman, G. E. The ecological and physiological action of ammonium salts on the clover content of turf. Ann. Botany 48: 975-1001. 1934.

5. Bonner, James. Plant Biochemistry. First Edition. 537 pp. Academic Press Inc., New York. 1950.

6. ____________, and A. W. Galston. Principles of Plant Physiology. First Edition. W. H. Freeman and Co., San Francisco. 1952.

7. Chibnall, A. C. Protein Metabolism in the Plant. First Edition. Yale University Press. New Haven. 1939.

8. Cook, J. A., and D. Boynton. Some factors affecting the absorption of urea by McIntosh apple leaves. Proc. Am. Soc. Hort. Sci. 59: 82-90. 1952.

9. Davis, M. B., and H. Hill. Tomatoes make known their diet needs. Bulletin. American Potash Institute, Inc., Investment Bldg., Washington, D.C.

10. Eckerson, S.H. Protein synthesis in plants I. Nitrate reduction. Bot. Gaz. 77: 377-390. 1924.

11. Ellis, C., and M. W. Swaney. Soil-less Growth of Plants. First Edition. 155 pp. Reinhold Publishing Corp., New York. 1938.

12. Emmert, E. M. Plant-tissue tests as a guide to fertilizer treatment of tomatoes. Ky. Agr. Expt. Sta. Bul. #430. June, 1942.

13. Emmert, E. M. Method for quickly determining nitrogen in plants, and soluble nitrogen, as a measure of the nitrogen available for anabolic processes. Plant Physiol. 10: 355-364. 1935.

14. ____________. Personal communication. March, 1952.

15. ____________ and C. S. Waltman. A rapid method for estimating soluble carbon contained in plant tissue extracts. Proc. Am. Soc. Hort. Sci. 41: 245-250. 1942.

16. ____________ and J. E. Klinker. Spraying tomato foliage with sucrose to increase carbohydrates and protect against injury by urea sprays. Ky. Agr. Expt. Sta. Bul. #550. May, 1950.

17. Fisher, E. G. The principles underlying foliage applications of urea for nitrogen fertilization of the McIntosh apple. Proc. Am. Soc. Hort. Sci. 59: 91-98. 1952.

18. ____________ and J. A. Cook. Nitrogen fertilization of the McIntosh apple with leaf sprays of urea. Proc. Am. Soc. Hort. Sci. 55: 35-40. 1950.

19. ____________, D. Boynton and K. Skodvin. Nitrogen fertilization of the McIntosh apple with leaf sprays of urea. Proc. Am. Soc. Hort. Sci. 51: 23-30. 1948.

20. Fleming, H. K., and R. B. Alderfer. Effects of urea and oil-wax.emulsion sprays on the performance of the Concord grapevine under cultivation and in Ladino clover sod. Proc. Am. Soc. Hort. Sci. 54: 171-176. 1949.

21. Ghosh, B. P., and R. H. Burris. Utilization of nitrogenous compounds by plants. Soil Sci. 70: 187-203. 1950.

22. Gregory, F. G., and P. K. Sen. Physiological studies in plant nutrition. VI - The relation of respiration rate to the carbohydrate and nitrogen metabolism of the barley leaf as determined by nitrogen and potassium deficiency. Ann. Botany ns. 1: 520-561. 1937.

23. Hamilton, J. M., D. H. Palmiter and L. C. Anderson. Preliminary tests with uramon in foliage sprays as a means of regulating the nitrogen supply of apple trees. Proc. Am. Soc. Hort. Sci. 42: 123-126. 1943.

24. Heinicke, A. J., and N. F. Childers. The daily rate of photosynthesis during the growing season of 1935, of a young apple tree of bearing age. Cornell Agr. Expt. Sta. Mem. 201. February, 1937.

25. ______________ and M. B. Hoffman. The rate of photosynthesis of apple leaves under natural conditions. Cornell Agr. Expt. Sta. Bul. #577. November, 1933.

26. Jones, W. W., and E. R. Parker. Preliminary report on use of urea as a nitrogen spray for orange trees. California Citrograph. September, 1949.

27. Kraus, E. J., and H. R. Kraybill. Vegetation and reproduction with special reference to the tomato. Oregon Agr. Expt. Sta. Bul. #149. 1918.

28. MacVicar, R., and R. H. Burris. Studies in tomato with use of isotopically labelled $(NH_4)_2SO_4$. Jour. Biol. Chem. 176: 511-516. 1948.

29. MacVicar, R. M., and D. R. Gibson. A preliminary investigation of orchard grass seed production as influenced by nitrogen applied as a spray. Sci. Agr. 31: 396-398. 1951.

30. _______________ _________________. Effect of sources of nitrogen, rates of application and method of application on seed production of orchard grass. Sci. Agr. 31: 399-412. 1951.

31. Magness, J. R. Fertilization - ground and foliage. Hoosier Horticulture 32: 51-58. April, 1950.

32. McKee, H. S. A review of recent work on the nitrogen metabolism of plants. New Phytologist 36: 240-266. 1937.

33. ____________. Review of recent work on nitrogen metabolism. New Phytologist 48: 1-83. 1949.

34. Meyer, B. S., and D. B. Anderson. Plant Physiology. First edition. 696 pp. D. Van Nostrand Co., New York. 1939.

35. Montelaro, J., C. B. Hall and F. S. Jamison. Studies on the nitrogen nutrition of tomatoes with foliar sprays. Proc. Am. Soc. Hort. Sci. 59: 361-366. 1952.

36. Nightingale, G. T. The nitrogen nutrition of green plants. Bot. Rev. 3: 85-174. 1937.

37. Nightingale, G. T. The nitrogen nutrition of green plants II. Bot. Rev. 14: 185-221. 1948.

38. ______________, L. G. Schermerhorn and W. R. Robbins. The growth status of the tomato as correlated with organic nitrogen and carbohydrates in roots, stems and leaves. N. J. Agr. Expt. Sta. Bul. #461. Sept., 1928.

39. ______________, ______________ ______________. Some effects of potassium deficiency on the histological structure and nitrogenous and carbohydrate constituents of plants. N. J. Agr. Expt. Sta. Bul. #499. April, 1930.

40. Noggle, G. R., and S. A. Watson. The relationship of riboflavin and ascorbic acid to carbohydrate and nitrogen fractions in immature oat plants as influenced by mineral deficiencies. Plant Physiol. 24: 265-277. 1949.

41. Phillips, T. F., T. O. Smith and R. B. Dearborn. The effect of potassium deficiency on the composition of the tomato plant. N. H. Agr. Expt. Sta. Tech. Bul. #59. June, 1934.

42. ______________, ______________ and J. R. Hepler. Some effects of potassium and nitrogen deficiency on the composition of the tomato plant. N. H. Agr. Expt. Sta. Tech. Bul. #73. April, 1939.

43. Pirone, P. P. Agr. News Letter 18: 97-99. November-December, 1950.

44. Reifer, I., and J. Melville. The source of ammonia in plant tissue extracts II. The influence of urea. Jour. Biol. Chem. 178: 715-726. 1949.

45. Roberts, E. A., M. D. Southwick and D. H. Palmiter. A microchemical examination of McIntosh apple leaves showing relationship of cell wall constituents to penetration of spray solutions. Plant Physiol. 23: 557-559. 1948.

46. Rodney, D. R. The entrance of nitrogen compounds through the epidermis of apple leaves. Proc. Am. Soc. Hort. Sci. 59: 99-102. 1952.

47. Smith, P. G., and F. W. Zink. Effect of sucrose foliage sprays on tomato transplants. Proc. Am. Soc. Hort. Sci. 58: 168-178. 1951.

48. Snedecor, G. W. Statistical Methods. Fourth edition. 485 pp. The Iowa State College Press., Ames, Iowa. 1946.

49. Sumner, J. B., and G. F. Somers. Chemistry and Methods of Enzymes. Second edition. 415 pp. Academic Press Inc., New York. 1947.

50. Tiedjens, V. A. Factors affecting assimilation of ammonium and nitrate nitrogen, particularly in tomato and apple. Plant Physiol. 9: 31-57. 1934.

51. Truog, E. Mineral Nutrition of Plants. First edition. 469 pp. University of Wisconsin Press, Madison. 1951.

52. Tukey, H. B., R. L. Tichnor, O. N. Hinsvark and S. H. Wittwer. Absorption of nutrients by stems and branches of woody plants. Science 116: 167-168. Aug. 15, 1952.

53. Vickery, H. B., G. W. Pucher and H. E. Clark. Glutamine in the tomato. Science ns. 80: 459-461. 1934.

54. ______________, ____________, R. Schoenheimer and D. Rittenburg. The assimilation of ammonia nitrogen by the tobacco plant: A preliminary study with isotopic nitrogen. Jour. Biol. Chem. 135: 531-539. 1940.

55. ______________, ____________, A. J. Wakeman and C. S. Leavenworth. Chemical investigations of the tobacco plant VI. Chemical changes that occur in leaves during culture in light and darkness. Conn. Agr. Expt. Sta. Bul. #399. August, 1937.

56. Viets, F. G., A. L. Moxon and E. I. Whitehead. Nitrogen metabolism of corn (<u>Zea mays</u>) as influenced by ammonium nutrition. Plant Physiol. 21: 271-289. 1946.

57. Wall, M. E. The role of potassium in plants III. Nitrogen and carbohydrate metabolism in potassium deficient plants supplied with either nitrate or ammonium nitrogen. Soil Sci. 49: 393-409. 1940.

58. Weinberger, J. H., V. E. Prince, and L. Havis. Tests on foliar fertilization of peach trees with urea. Proc. Am. Soc. Hort. Sci. 53: 26-28. 1949.

59. Went, F. W., and M. Carter. Growth response of tomato plants to applied sucrose. Am. Jour. Bot. 35: 95-106. 1948.

60. Yemm, E. W. Glutamine in the metabolism of barley plants. New Phytologist 48: 315-331. 1949.

APPENDIX A - I

South							North
	(10)	(1)	(10)	(1)	(10)	(1)	
	(9)	(2)	(9)	(2)	(9)	(2)	
	(8)	(3)	(8)	(3)	(8)	(3)	
	(7)	(4)	(7)	(4)	(7)	(4)	
	(6)	(5)	(6)	(6)	(6)	(5)	
	BLOCK III		BLOCK II		BLOCK I		

(1) Check	(6) 0.5 M. Sucrose
(2) 0.1 M. Urea	(7) 1.0 M. Sucrose
(3) 0.5 M. Urea	(8) 0.1 M. Urea + 0.1 M. Sucrose
(4) 1.0 M. Urea	(9) 0.5 M. Urea + 0.5 M. "
(5) 0.1 M. Sucrose	(10) 1.0 M. Urea + 1.0 M. "

Plan of the experimental field plot used for preliminary trials of urea and sucrose foliage sprays on tomato plants.

APPENDIX A - II

Soluble carbon levels in tomato leaves of plants receiving three concentrations of urea, sucrose and urea-sucrose foliage sprays, as shown by tests made at two spray test-date intervals. Data are expressed as p.p.m. of fresh leaf sample.

C A R B O N

		1 Wk. After Spraying			3 Wks. After Spraying		
		1 Spray	2 Spray	3 Spray*	1 Spray	2 Spray*	3 Spray
	Check	--	2850	3550	2850	3550	800
	0.1 M. Urea	--	5400	2880	5400	2880	2400
	0.5 M. Urea	--	4500	6150	4500	6150	3150
	1.0 M. "	--	3150	2150	3150	2150	1350
BLOCK I	0.1 M.Sucrose	--	3670	4750	3670	4750	3250
	0.5 "	--	4700	2850	4700	2850	3750
	1.0 "	--	4400	2750	4400	2750	1950
	0.1 M.(U + S)	--	4650	2800	4650	2800	3800
	0.5 "	--	6100	2000	6100	2000	1950
	1.0 "	--	6920	6150	6920	6150	1550
	Check	3950	2000	--	2000	2300	--
	0.1 M. Urea	3750	3100	--	3100	1400	--
	0.5 "	3150	3800	--	3800	1850	--
	1.0 "	5550	2700	--	2700	3150	--
BLOCK II	0.1 M.Sucrose	4550	3400	--	3400	4050	--
	0.5 "	3150	3150	--	3150	3750	--
	1.0 "	4500	2050	--	2050	1900	--
	0.1 M.(U + S)	6900	4250	--	4250	3150	--
	0.5 "	5350	7350	--	7350	6650	--
	1.0 "	5900	3500	--	3500	4150	--
	Check	1700	--	--	3900	--	--
	0.1 M. Urea	6950	--	--	3250	--	--
	0.5 "	2800	--	--	1700	--	--
	1.0 "	3300	--	--	2850	--	--
BLOCK III	0.1 M.Sucrose	3200	--	--	500	--	--
	0.5 "	3400	--	--	2500	--	--
	1.0 "	3550	--	--	750	--	--
	0.1 M.(U + S)	4400	--	--	3350	--	--
	0.5 "	4250	--	--	2950	--	--
	1.0 "	2350	--	--	5500	--	--

* Weather dull and cloudy for 2 days previous, and day of test.

APPENDIX A - III

Soluble nitrogen levels in tomato leaves of plants receiving three concentrations of urea, sucrose and urea-sucrose foliage sprays, as shown by tests made at two spray test-date intervals. Data are expressed as p.p.m. of fresh leaf sample.

N I T R O G E N

		1 Wk. After Spraying			3 Wks. After Spraying		
		1 Spray	2 Spray	3 Spray*	1 Spray	2 Spray	3 Spray
BLOCK I	Check	--	158	261	158	261	30
	0.1 M. Urea	--	414	440	414	440	11
	0.5 M. "	--	178	165	178	165	0
	1.0 M. "	--	130	509	130	509	20
	0.1 M.Sucrose	--	0	172	0	172	0
	0.5 M. "	--	0	550	0	550	0
	1.0 M. "	--	178	248	178	248	28
	0.1 M.(U + S)	--	0	633	0	633	0
	0.5 M. "	--	0	757	0	757	0
	1.0 M. "	--	440	289	440	289	0
BLOCK II	Check	110	103	--	103	0	--
	0.1 M. Urea	83	248	--	248	29	--
	0.5 M. "	138	0	--	0	21	--
	1.0 M. "	42	28	--	28	14	--
	0.1 M.Sucrose	0	55	--	55	13	--
	0.5 M. "	55	124	--	124	13	--
	1.0 M. "	0	702	--	702	17	--
	0.1 M. (U + S)	0	124	--	124	13	--
	0.5 M. "	0	0	--	0	0	--
	1.0 M. "	0	275	--	275	0	--
BLOCK III	Check	193	--	--	0	--	--
	0.1 M. Urea	55	--	--	13.2	--	--
	0.5 M. "	275	--	--	22.0	--	--
	1.0 M. "	42	--	--	0	--	--
	0.1 M.Sucrose	220	--	--	29.7	--	--
	0.5 M. "	330	--	--	25.3	--	--
	1.0 M. "	152	--	--	49.5	--	--
	0.1 M.(U + S)	0	--	--	27.5	--	--
	0.5 M. "	0	--	--	0	--	--
	1.0 M. "	179	--	--	12.1	--	--

* Weather dull and cloudy for 2 days previous, and day of test.

APPENDIX B

Data for 1952 Summer Greenhouse Experiment.
(All yields are given in grams.)

Table I

Early Ripe Fruit Yield (Aug. 26)

	TREATMENT			
Rep.	NO_3 (R)	Urea (R)	Urea (S)	(U+S)(S)
1	182.2	253.1	213.4	242.4
2	150.0	76.3	231.4	76.9
3	108.5	103.7	0.0	137.9
4	74.9	251.2	192.5	0.0
5	0.0	173.9	0.0	160.7
6	212.9	188.2	241.9	280.5
Sum	728.5	1,046.4	879.2	898.4
Mean	121.4	174.4	146.5	149.7

Table II

Final Fruit Harvest (Sept. 3)

1	120.8	67.6	116.4	74.1
2	133.6	197.5	82.6	175.8
3	212.1	237.7	266.9	176.4
4	293.0	0.0	155.7	293.3
5	253.7	188.8	281.7	135.2
6	139.8	164.8	127.0	46.1
Sum	1,153.0	856.4	1,030.3	900.9
Mean	192.2	142.7	171.7	150.2

APPENDIX B
(cont'd)

Table III

Total Fruit Yield

	TREATMENT			
Rep.	NO_3(R)	Urea (R)	Urea (S)	(U + S)(S)
1	303.0	320.7	329.8	316.5
2	283.6	273.8	314.0	252.7
3	320.6	341.4	266.9	314.3
4	367.9	251.2	348.2	293.3
5	253.7	362.7	281.7	295.9
6	352.7	353.0	368.9	326.6
Sum	1,881.5	1,902.8	1,909.5	1,799.3
Mean	313.6	317.1	318.3	299.9

Table IV

Total Ripe Fruit Yield

1	261.8	253.1	329.8	273.4
2	242.7	186.1	314.0	252.7
3	257.8	312.0	172.7	295.0
4	293.0	251.2	314.7	234.2
5	233.7	272.7	232.6	247.5
6	266.3	254.0	293.4	280.5
Sum	1,555.3	1,529.1	1,657.2	1,583.3
Mean	259.2	254.9	276.2	263.9

APPENDIX B
(cont'd)

Table V

Final Dry Weight (Plant Tops)

	TREATMENT			
Rep.	NO_3(R)	Urea (R)	Urea (S)	(U + S)(S)
1	6.06	7.04	6.66	6.37
2	7.14	5.43	5.02	8.62
3	9.58	7.52	8.25	6.81
4	10.68	4.87	7.89	6.61
5	8.06	6.59	11.47	6.42
6	8.14	11.44	9.06	6.80
Sum	49.66	42.89	48.35	41.63
Mean	8.28	7.15	8.06	6.94

Table VI

Final Dry Weight (Plant Roots)

1	2.28	2.06	1.62	2.55
2	2.31	1.49	1.30	1.77
3	2.54	1.89	2.01	1.76
4	2.75	1.28	1.92	1.44
5	1.56	1.75	2.46	1.57
6	2.12	2.56	2.59	1.24
Sum	13.56	11.03	11.90	10.33
Mean	2.26	1.84	1.98	1.72

APPENDIX B
(cont'd)

Table VII. Fresh weight (grams) of tops, roots and fruit harvested from 1952 summer greenhouse experiment, as well as initial starting weights of plants utilized, plus increment in fresh weight during the experiment.

Rep.	NO_3(R)					Urea (R)				
	Initial	Top	Root	Fruit	Incr.	In.	Top	Root	Fruit	Incr.
1	7.4	38.0	20.1	303.0	353.7	7.8	51.6	18.1	320.7	382.6
2	7.1	40.6	19.8	283.6	336.9	4.8	34.7	15.3	273.8	319.0
3	4.1	49.4	20.8	320.6	386.7	3.5	48.4	17.3	341.4	403.6
4	3.6	64.0	23.1	367.9	451.4	7.5	20.0	13.5	251.2	277.2
5	5.8	52.7	14.6	253.7	315.2	5.8	47.2	16.2	362.7	420.3
6	6.8	52.7	18.2	352.7	416.8	8.0	71.7	21.7	353.0	438.4
Mean	5.8	49.6	19.4	313.6	376.8	6.2	45.6	17.0	317.1	373.5

Rep.	Urea (S)					(U + S)(S)				
	Initial	Top	Root	Fruit	Incr.	In.	Top	Root	Fruit	Incr.
1	6.2	39.6	12.8	329.8	376.0	4.3	31.0	20.1	316.5	363.3
2	6.5	20.1	13.0	314.0	340.6	5.0	31.6	15.3	252.7	294.6
3	5.1	47.5	20.0	266.9	329.3	4.6	33.4	17.9	314.3	361.0
4	6.0	54.8	20.5	348.2	417.5	3.4	36.6	14.1	293.3	340.6
5	4.0	69.8	26.4	281.7	373.9	5.6	29.3	17.0	295.9	336.6
6	6.0	52.9	21.8	368.9	437.6	4.8	37.4	11.4	326.6	370.6
Mean	5.6	47.5	19.1	318.3	379.2	4.6	33.2	16.0	299.9	344.5

APPENDIX B
(cont'd)

Table VIII. Results of Analyses of Variance on data of 1952 summer greenhouse experiment. (F for significance = 3.29 at 5% level)

Source of Variation	D.F.	S.S.	M.S.	F.
(a) Early Ripe Fruit Yield				
Total	23	1,848,083		
Treatments	3	84,527	28,176	0.45
Replicates	5	832,014	166,403	2.68
Error	15	931,542	62,103	
(b) Total Fruit Yield				
Total	23	3,167		
Treatments	3	128	42.7	0.32
Replicates	5	1,060	212.0	1.61
Error	15	1,979	131.9	
(c) Total Increase in Fresh Weight				
Total	23	50,302.2		
Treatments	3	4,713.6	1,571.2	1.06
Replicates	5	17,579.1	3,515.8	2.37
Error	15	22,292.7	1,486.2	
(d) Final Fresh Weight (Plant Tops)				
Total	23	4,359.04		
Treatments	3	970.34	323.45	2.19
Replicates	5	1,171.20	234.24	1.58
Error	15	2,217.50	147.83	
(e) Final Fresh Weight (Plant Roots)				
Total	23	316.46		
Treatments	3	49.60	16.53	1.02
Replicates	5	23.99	4.80	0.30
Error	15	242.87	16.19	
(f) Final Dry Weight (Plant Tops)				
Total	23	76.08		
Treatments	3	7.86	2.62	0.77
Replicates	5	17.24	3.45	1.01
Error	15	50.98	3.40	
(g) Final Dry Weight (Plant Roots)				
Total	23	5.039		
Treatments	3	0.971	0.324	1.40
Replicates	5	0.603	0.121	0.52
Error	15	3.465	0.231	

APPENDIX C

Table I. Levels of soluble carbon (p.p.m. fresh-weight basis) present in tomato leaves during a 12-day period following given spray treatments. (First test period.)

	TREATMENT							
	Check		Urea		Sucrose		(U + S)	
Day	1 *	2	1	2	1	2	1	2
1	1312	2392	1392	2863	1622	2472	1702	1507
2	2128	1553	875	1243	2495	990	2334	2047
3	2461	1645	1691	1898	2013	3564	1886	2553
4	1438	1277	1900	1967	2013	2507	1208	2059
6	3001	2449	875	1415	1174	1760	1507	1898
8	2618	2686	875	1276	1967	2664	2090	2251
10	1723	1207	1276	1391	1632	2366	1999	2618
12	3019	2377	2767	2205	1837	4556	2974	2905

* Replicates.

Note - 12-day data were not included in the statistical analysis.

APPENDIX C
(cont'd)

Table II. Levels of soluble nitrogen (p.p.m. fresh-weight basis) present in tomato leaves during a 12-day period following given spray treatments. (First test period.)

	TREATMENT							
	Check		Urea		Sucrose		(U + S)	
Day	1 *	2	1	2	1	2	1	2
1	520	280	3140	1260	660	630	610	950
2	270	140	780	560	110	370	540	580
3	270	260	680	890	220	320	890	400
4	290	265	320	460	340	130	330	690
6	310	240	10-	10-	210	600	380	620
8	310	580	620	610	760	660	510	700
10	10-	30	470	580	270	510	400	450
12	420	240	320	240	70	620	490	270

* Replicates.

<u>Note</u> - 12-day data were not included in the statistical analysis.

APPENDIX C
(cont'd)

Table III. Levels of soluble carbon (p.p.m. fresh-weight basis) present in tomato leaves during a 10-day period following given spray treatments. (Second test period.)

	TREATMENT							
	Check		Urea		Sucrose		(U + S)	
	1 *	2	1	2	1	2	1	2
1	2274	1895	1322	932	1379	1609	1379	1872
2	2078	2446	978	1161	2262	1861	748	2790
3	691	250⁻	576	250⁻	725	817	250⁻	783
4	2159	886	2274	1276	1815	1758	1184	2274
6	2756	1517	2480	2813	2710	2182	2813	886
8	2882	2893	2641	3134	2331	3352	1850	3650
10	3100	2159	2343	2595	1987	2182	2239	2893

* Replicates.

APPENDIX C
(cont'd)

Table IV. Levels of soluble nitrogen (p.p.m. fresh-weight basis) present in tomato leaves during a 10-day period following given spray treatments. (Second test period.)

	TREATMENT							
	Check		Urea		Sucrose		(U + S)	
Day	1 *	2	1	2	1	2	1	2
1	550	180	1010	450	550	410	600	780
2	130	160	1230	950	90	150	910	1240
3	500	1170	1780	910	310	470	1300	1020
4	180	620	710	1020	170	290	540	650
6	260	430	1150	240	170	110	470	690
8	250	30	320	10-	120	10-	230	125
10	200	10-	290	90	30	50	20	20

* Replicates.

APPENDIX C
(cont'd)

Table V. Average height and spread measurements of tomato plants in each treatment unit on two dates during the experimental period. (All data in inches.)

JULY 31

	TREATMENT							
	Check		Urea		Sucrose		(U + S)	
Rep.	Height	Spread	Height	Spread	Height	Spread	Height	Spread
1	17	30	16	24	17	30	17	30
2	17	31	18	31	17	29	20	31
3	18	29	18	30	16	26	19	28
4	16	27	16	26	14	23	15	22
5	16	29	16	22	16	25	15	23
6	16	26	16	25	16	24	16	25
Mean	16.7	28.7	16.7	26.3	16	26.2	17	26.5

SEPT. 8

	TREATMENT							
	Check		Urea		Sucrose		(U + S)	
Rep.	Height	Spread	Height	Spread	Height	Spread	Height	Spread
1	19	51	14	33	17	46	19	41
2	18	46	15	38	15	45	18	52
3	23	44	18	46	19	49	14	47
4	19	51	15	46	13	41	17	39
5	17	51	15	41	18	45	17	38
6	17	46	16	41	14	46	16	44
Mean	18.8	48.2	15.5	40.8	16.0	45.3	16.8	43.5

APPENDIX C
(cont'd)

Table VI. Ripe and green fruit yields obtained from the 1952 summer field experiment. (All data given in pounds.)

	TREATMENT							
	Check		Urea		Sucrose		(U + S)	
Rep.	Ripe	Green	Ripe	Green	Ripe	Green	Ripe	Green
1	4.4	33.4	2.1	20.2	3.0	37.6	4.8	31.0
2	2.5	37.8	6.0	27.0	4.9	27.2	2.6	36.2
3	2.8	30.6	3.9	33.8	4.3	26.0	2.0	25.5
4	3.1	30.6	2.6	21.5	3.5	14.8	5.3	18.0
5	5.3	20.2	3.1	16.6	4.4	23.2	2.5	17.5
6	2.9	16.0	3.3	14.8	3.4	18.0	2.5	18.2
Mean	3.5	28.1	3.5	22.3	3.9	24.5	3.3	24.4

APPENDIX C
(cont'd)

Table VII. Levels of soluble carbon and soluble nitrogen (p.p.m. fresh-weight basis) present in mature green fruits - 1952 field experiment.

		TREATMENT			
		Check	Urea	Sucrose	(U + S)
CARBON	Rep. #1	6288	6833	5943	7490
		6173	6115	5915	7263
	Rep. #2	5225	7663	5655	5943
		5255	9040	5168	5743
	Mean	5735	7413	5670	6610
NITROGEN	Rep. #1	55	90	110	5-
		15	25	5-	5-
	Rep. #2	85	75	5-	35
		70	5-	55	15
	Mean	56	49	44	15

APPENDIX C
(cont'd)

Table VIII. Levels of soluble carbon and soluble nitrogen (p.p.m. fresh-weight basis) present in ripe fruits - 1952 field experiment.

		TREATMENT			
		Check	Urea	Sucrose	(U+S)
CARBON	Rep. #1	7865	5655	5973	4250
		8265	5313	6345	3738
	Rep. #2	8610	6660	7923	8208
		8553	6388	8380	7893
	Mean	8323	5979	7155	6022
NITROGEN	Rep. #1	5^{-}	5^{-}	5^{-}	5^{-}
		5^{-}	5^{-}	5^{-}	5^{-}
	Rep. #2	5^{-}	5^{-}	5^{-}	5^{-}
		5^{-}	5^{-}	5^{-}	5^{-}
	Mean	5^{-}	5^{-}	5^{-}	5^{-}

APPENDIX C
(cont'd)

Table IX. Weather observations prior to and during the first and second test periods - 1952 field experiment.

Days After Spray	First Period	Second Period
-2	Rainy	A.M. - cloud, P.M. - sun.
-1	Rainy	Sunny.
0	Sunny	Cloud to 4 P.M., then sunny.
1	"	Fog to 6:30 A.M., then sunny.
2	"	Sunny.
3	"	Cloudy A.M., some sun P.M.
4	"	Fog to 9 A.M., then sunny.
5	"	Sunny.
6	"	Sunny.
7	"	Sunny.
8	"	Sunny.
9	"	1/2 cloudy A.M., cloud + rain 6 P.M.
10	"	Cloudy A.M.
11	A.M. - cloud, P.M. - sun.	
12	Sunny	

APPENDIX C
(cont'd)

Table X. (a) Results of Analysis of Variance for soluble carbon data of Tables 1 and 3.

Source Variation	D.F.	S.S.	M.S.	F	F for Sig. 5%	1%
Replicates	1	6,804	6,804	2.12	4.02	
Treatments	3	25,662	8,554	2.66	2.78	
Dates of Spray	1	76	76	<1		
Days of Sampling	6	110,163	18,361	<1		
Tr. x Dates	3	9,343	3,114	<1		
Tr. x Samples	18	49,943	2,774	<1		
Dates x Samples	6	169,322	28,220	8.79**	2.27	3.15
Tr. x Dates x Samples	18	57,905	3,217	1.0		
Error	55	176,581	3,211			
Total	111	605,799				

	L.S.D. 5%	L.S.D. 1%	Significance
Dates x Samples	568	758	Day 3**, 6**, 7*

APPENDIX C
(cont'd)

Table X. (b) Results of Analysis of Variance for soluble nitrogen data of Tables 1 and 3.

Source Variation	D.F.	S.S.	M.S.	F	F for Sig. 5%	F for Sig. 1%
Replicates	1	440	440	<1		
Treatments	3	38,586	12,862	8.60**	2.78	5.09
Dates of Spray	1	246	246	<1		
Days of Sampling	6	39,334	6,556	1.33		
Tr. x Dates	3	3,105	1,035	<1		
Tr. x Samples	18	27,696	1,538	1.03		
Dates of Samples	6	29,558	4,926	3.29*	2.66	
Tr. x Dates x Samples	18	26,927	1,496	2.19*	1.80	
Error	55	37,490	682			
Total	111	203,382				

	L.S.D. 5%	L.S.D. 1%	Significance
Treatments	217	297	Urea* and (U + S)** means.
Dates x Samples	408	558	Days 1*, 3* and 8*.
Tr. x Dates x Samples	524	699	(1) Urea Tr., Day 1 of first period** (2) " " Day 2 of second period** (3) (U+S) " Day 2 of second period**

APPENDIX C
(cont'd)

Table X. (c) Results of Analysis of Variance of ripe fruit yield data of Table 6.

Source Variation	D.F.	S.S.	M.S.	F	(F - 5%)
Total	23	29.0			
Treatments	3	1.2	0.4	0.24	3.29
Replicates	5	2.6	0.52	0.31	2.90
Error	15	25.2	1.68		

Table X. (d) Results of Analysis of Variance of total fruit yield data as calculated from Table 6.

Source Variation	D.F.	S.S.	M.S.	F	(F - 1%)
Total	23	1364.2			
Treatments	3	104.6	34.9	1.38	
Replicates	5	879.8	175.9	6.95**	4.56
Error	15	379.8	25.3		

APPENDIX C
(cont'd)

Table X. (e) Data and results of Tests of Correlation (data of Tables 1, 2, 3 and 4 used; data rounded to 3 and 2 significant figures for soluble carbon and nitrogen, respectively).

Variable X = carbon.

Variable Y = nitrogen.

	TREATMENT			
Item	Check	Urea	Sucrose	(U + S)
ΣX	5,587	4,572	5,617	5,379
$\Sigma(X)^2$	1,262,179	902,676	1,247,047	1,189,737
ΣY	845	2,055	871	1,665
$\Sigma(Y)^2$	40,951	260,055	39,943	126,273
ΣXY	145,829	300,074	165,464	287,682

Treatment	"r" Value
Check	-0.477*
Urea	-0.272
Sucrose	-0.236
(U + S)	-0.492**

"r" for Significance - 5% level = 0.374

- 1% level = 0.478

APPENDIX D

Table 1. Consolidated data of 1952 fall greenhouse experiment including initial starting weights of plants, final fresh weights of plant tops, roots and fruit, plus increment in fresh weight during the experiment. (All data in grams.)

Rep.	NO_3 (R)					Urea (R)				
	Initial	Top	Root	Fruit	Incr.	In.	Top	Root	Fruit	Incr.
1	11.6	25.4	8.1	132.5	154.4	9.1	14.7	6.5	71.2	83.3
2	9.8	34.4	10.2	91.5	126.3	8.6	29.5	8.0	122.5	151.4
3	6.7	29.2	10.6	75.8	108.9	8.5	48.8	15.3	91.1	146.7
4	10.1	15.5	7.3	87.5	100.2	6.9	28.2	8.7	50.0	80.0
5	10.0	18.8	6.9	77.0	92.7	9.4	40.6	11.4	135.8	178.4
6	11.6	30.3	9.6	95.0	123.3	11.4	35.6	10.5	130.4	165.1
Mean	10.0	25.6	8.6	93.3	117.6	9.0	32.9	10.1	100.3	134.2

Rep.	Urea (S)					(U + S)(S)				
	Initial	Top	Root	Fruit	Incr.	In.	Top	Root	Fruit	Incr.
1	9.0	19.5	8.1	96.6	115.2	8.3	43.3	17.3	84.6	136.9
2	9.8	25.0	11.2	91.7	118.1	6.9	38.2	15.0	72.7	119.0
3	11.5	25.5	10.3	135.0	159.3	7.6	22.9	10.8	57.8	83.9
4	9.4	24.6	9.7	161.5	186.4	7.9	32.6	11.3	71.3	107.3
5	7.9	32.3	12.2	79.5	116.1	7.8	34.0	10.6	92.3	129.1
6	6.7	39.2	12.9	58.5	103.9	7.0	39.7	13.8	30.2	76.7
Mean	9.1	27.7	10.7	103.8	133.2	7.6	35.1	13.1	68.2	108.8

APPENDIX D (cont'd)

Table II. Ripe, green and total yields (grams) of tomato fruits harvested from the 1952 fall greenhouse experiment, including number of fruits in each category.

	T R E A T M E N T							
	NO_3 (R)		Urea (R)		Urea (S)		(U + S)(S)	
Rep. No.	Ripe	Green	Ripe	Green	Ripe	Green	Ripe	Green
1	3* - 132.5	--	1 - 58.2	1 - 13.0	1 - 96.6	--	--	4 - 84.6
2	1 - 76.5	1 - 15.0	2 -122.5	--	1 - 63.5	2 - 28.2	--	1 - 72.7
3	1 - 45.8	1 - 30.0	1 - 16.6	3 - 74.5	2 -135.0	--	--	3 - 57.8
4	2 - 87.5	--	1 - 50.0	--	2 -126.5	2 - 35.0	1 - 71.3	--
5	1 - 77.0	--	1 -116.8	2 - 19.0	--	4 - 79.5	--	6 - 92.3
6	1 - 95.3	--	2 -127.9	2 - 3.5	--	5 - 58.5	--	4 - 30.2
Sum	9 - 514.6	2 - 45.0	8 -492.0	9 -110.0	6 -421.6	13-201.2	1 - 71.3	18-337.6
Mean	1.5- 85.8	0.3-7.5	1.3-82.0	1.5-18.3	1 - 70.3	2.2-33.5	0.2-11.9	3.0-56.3
Total Yield (R + G)								
Sum	559.6		602.0		622.8		409.8	
Mean	93.3		100.3		103.8		68.2	
% Ripened Fruit	92.0		81.5		67.7		17.5	

* Number of fruits harvested for yield indicated.

APPENDIX D
(cont'd)

Table III. Dry weight in grams of root and top material from 1952 fall greenhouse experiment.

	TREATMENT							
	NO_3 (R)		Urea (R)		Urea (S)		(U + S)(S)	
Rep.	Root	Top	Root	Top	Root	Top	Root	Top
1	0.956	3.263	0.825	3.882	0.942	2.775	1.989	6.783
2	1.193	3.977	0.836	3.247	1.406	3.668	1.548	5.531
3	0.978	3.351	1.916	5.578	1.198	3.469	1.115	3.759
4	0.744	1.868	0.835	3.266	0.948	4.048	1.461	4.329
5	1.043	2.432	1.288	4.111	1.531	4.709	1.258	4.981
6	1.366	3.324	1.194	4.368	1.554	4.868	1.773	5.948
Mean	1.047	3.036	1.149	4.075	1.263	3.923	1.524	5.222**
Mean (R+T)	4.083		5.224		5.186		6.746	

** Increase highly significant statistically.

APPENDIX D
(cont'd)

Table IV. Results of Analyses of Variance on data of 1952 fall greenhouse experiment. (F for treatments significance = 3.29 (5%); 5.42 (1%).)

Source of Variation	D.F.	S.S.	M.S.	F.
(a) Final Fresh Weight (Plant Tops)				
Total	23	1,794.32		
Treatments	3	354.31	118.10	1.62
Replicates	5	346.21	69.24	0.95
Error	15	1,093.80	72.92	
(b) Final Fresh Weight (Plant Roots)				
Total	23	130.74		
Treatments	3	59.97	19.99	5.91**
Replicates	5	20.13	4.03	1.19
Error	15	50.64	3.38	
L.S.D. - 1% level = 3.1; 5% level = 2.3				
Differing treatment means - (U + S)(S) = 13.1**				
(c) Total Fruit Yield				
Total	23	22,491.0		
Treatments	3	4,646.8	1,548.9	1.37
Replicates	5	901.5	180.3	0.16
Error	15	16,942.3	1,129.5	
(d) Total Increase in Fresh Weight				
Total	23	22,680.5		
Treatments	3	3,157.9	1,052.6	0.84
Replicates	5	916.5	183.3	0.15
Error	15	18,606.1	1,240.4	
(e) Final Dry Weight (Plant Tops)				
Total	23	30.249		
Treatments	3	14.506	4.84	5.76**
Replicates	5	3.211	0.64	0.76
Error	15	12.532	0.84	
L.S.D. - 1% level = 1.559; 5% level = 1.127				
Differing treatment means - (U + S)(S) = 5.222**				
(f) Final Dry Weight (Plant Roots)				
Total	23	2.8037		
Treatments	3	0.7604	0.2535	2.44
Replicates	5	0.4875	0.0975	0.09
Error	15	1.5558	0.1037	

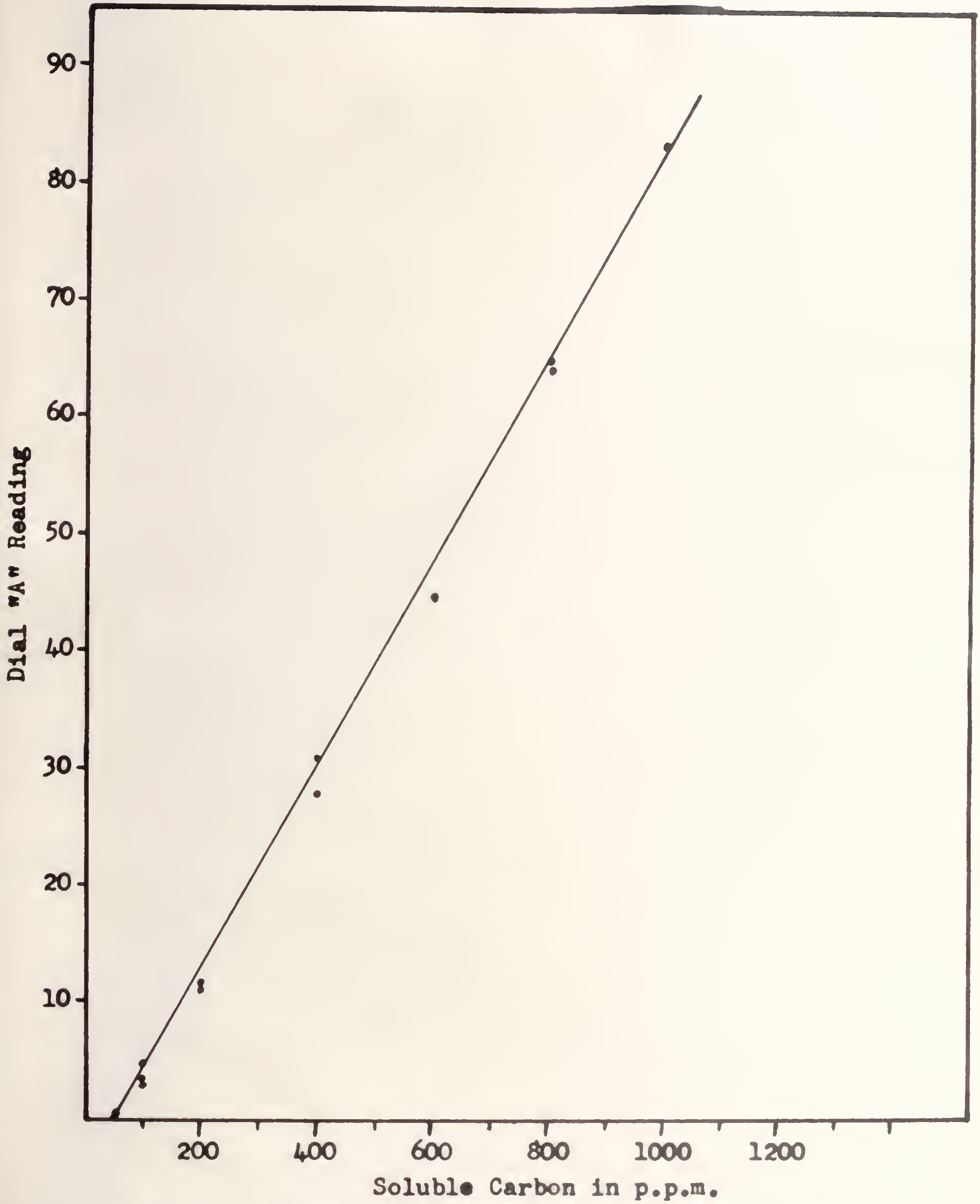

Figure 1. Calibration curve established July 8, 1952, for soluble carbon determination with the Fisher AC Model Electrophotometer, utilizing standard C.P. sucrose solutions containing 1000, 800, 600, 400, 200, 100 and 50 p.p.m. nitrogen.

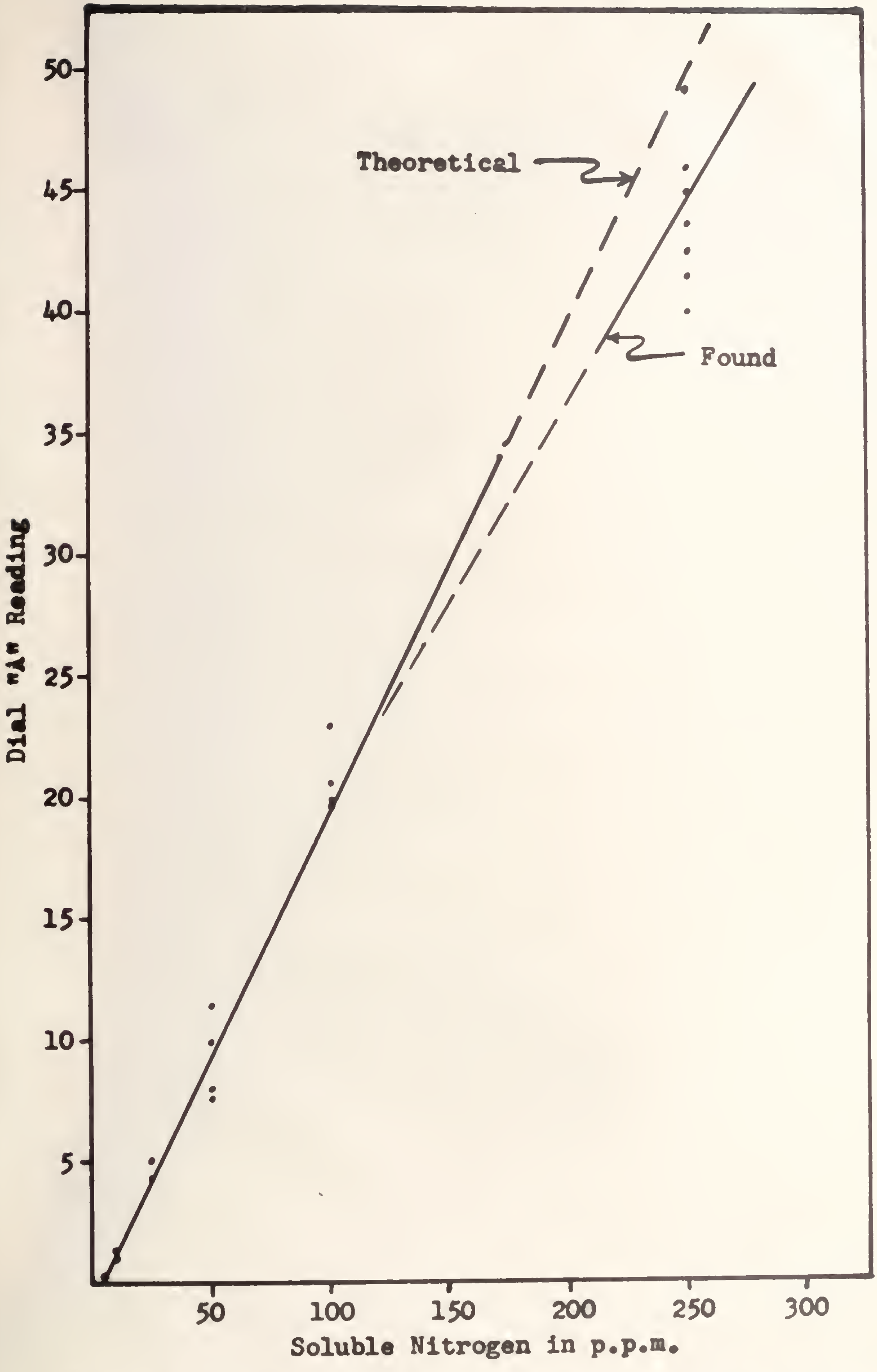

Figure 2. Calibration curve established July 17, 1952, for soluble nitrogen determination with the Fisher AC Model Electrophotometer, utilizing standard C.P. KNO_3 solutions containing 250, 100, 50, 25, 10 and 5 p.p.m. nitrogen.